

JET PROPULSION

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AMERICAN ROCKET SOCIETY

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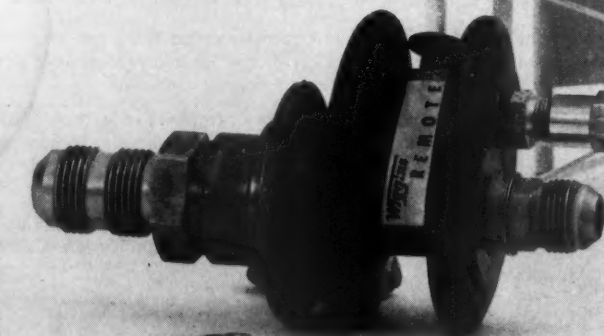
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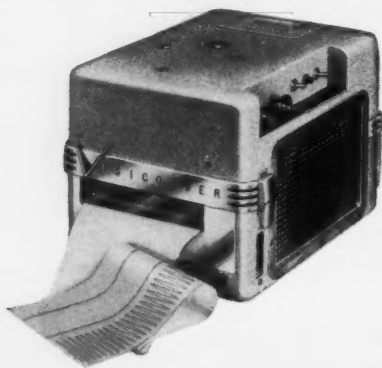
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JET PROPULSION, the Journal of the American Rocket Society, is devoted to the advancement of the field of jet propulsion through the publication of original papers disclosing new knowledge and new developments. The term "jet propulsion" as used herein is understood to embrace all engines that develop thrust by rearward discharge of a jet through a nozzle or duct; and thus it includes systems utilizing atmospheric air and underwater systems, as well as rocket engines. JET PROPULSION is open to contributions, either fundamental or applied, dealing with specialized aspects of jet and rocket propulsion, such as fuels and propellants, combustion, heat transfer, high temperature materials, mechanical design analyses, flight mechanics of jet-propelled vehicles, astronautics, and so forth. JET PROPULSION endeavors, also, to keep its subscribers informed of the affairs of the Society and of outstanding events in the rocket and jet propulsion field.

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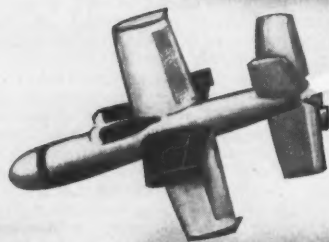


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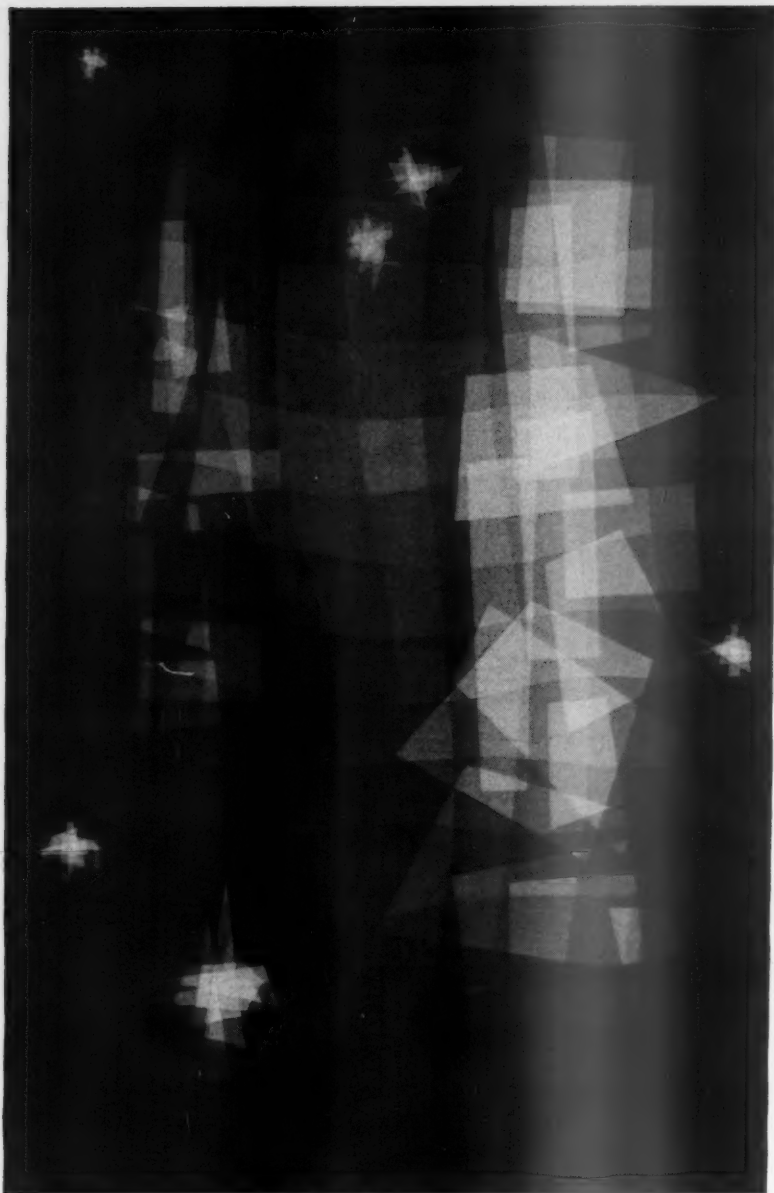
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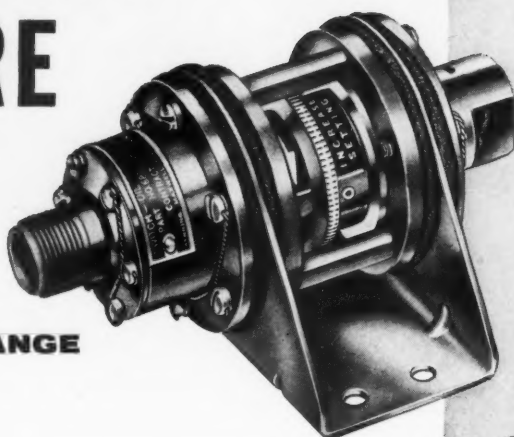
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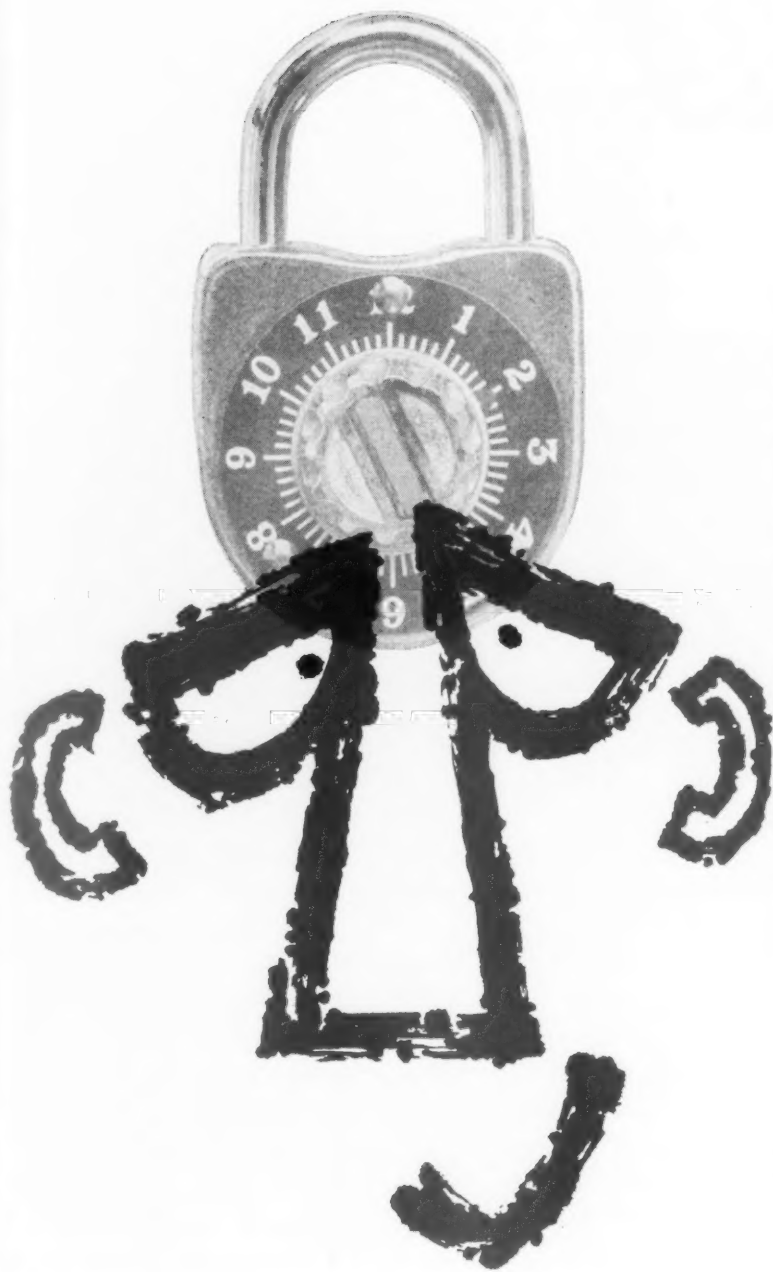
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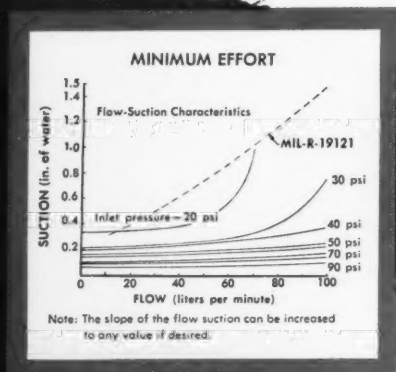
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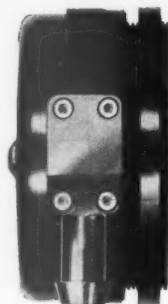
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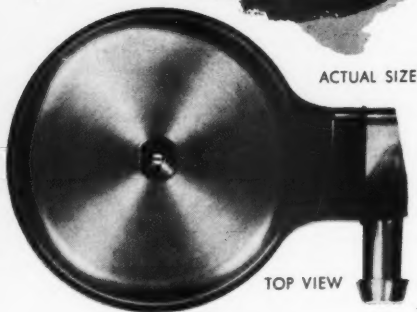
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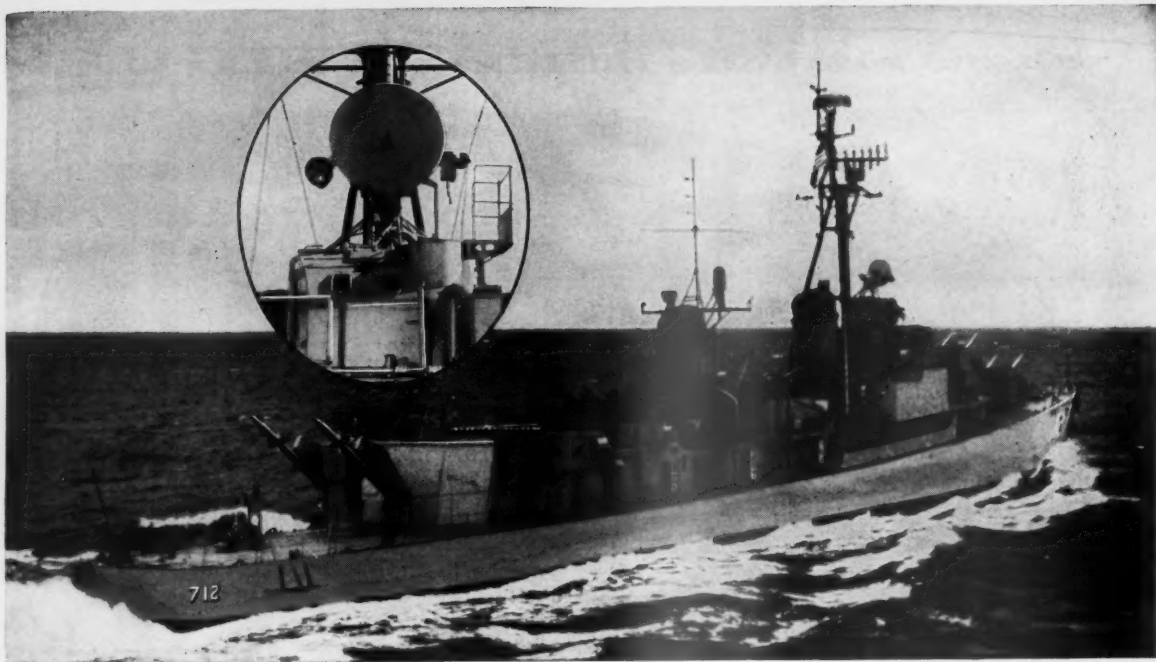
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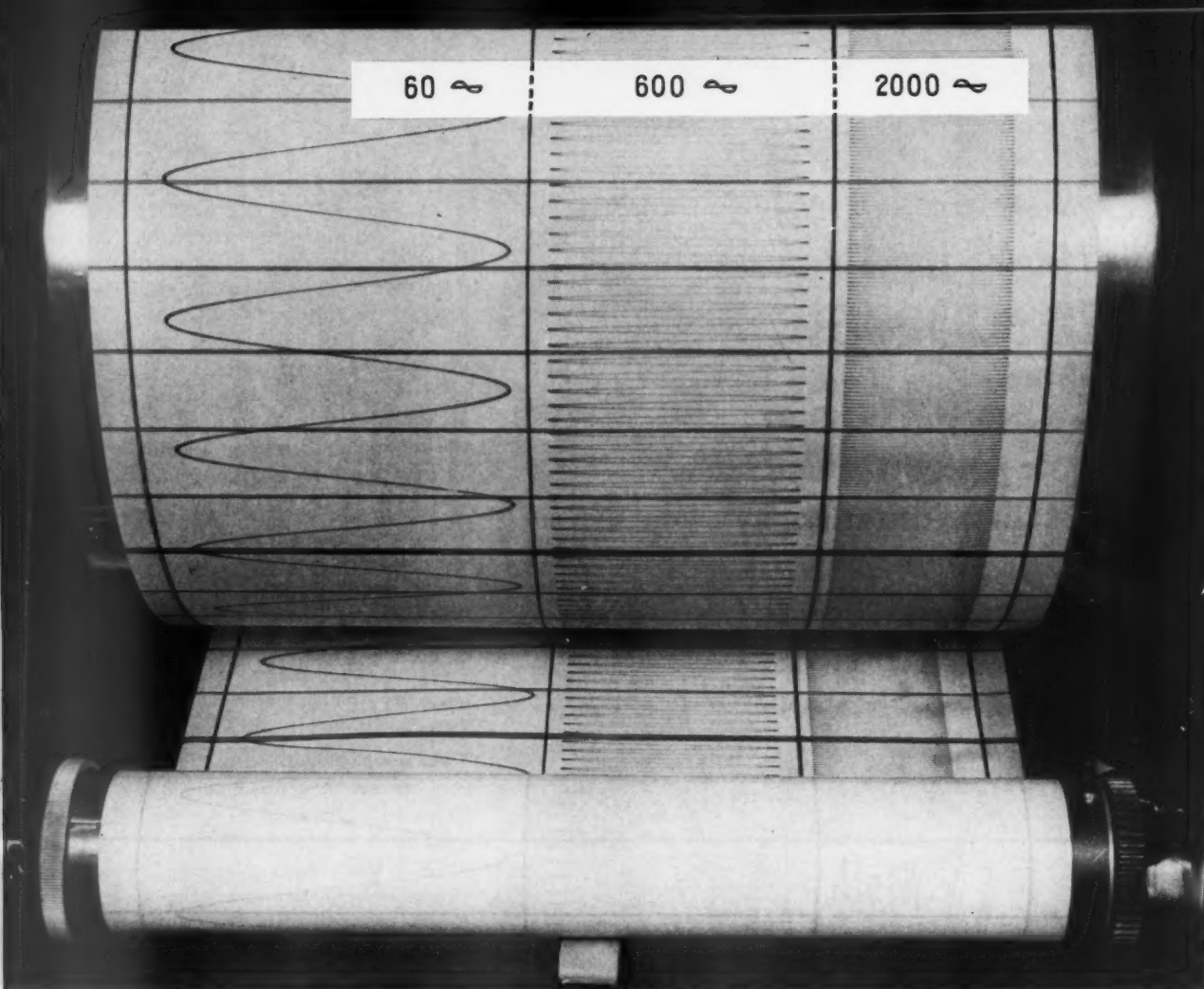
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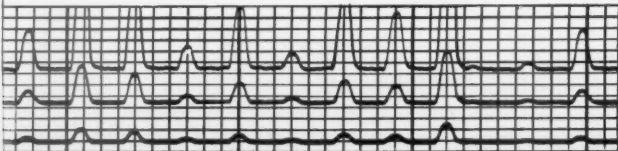
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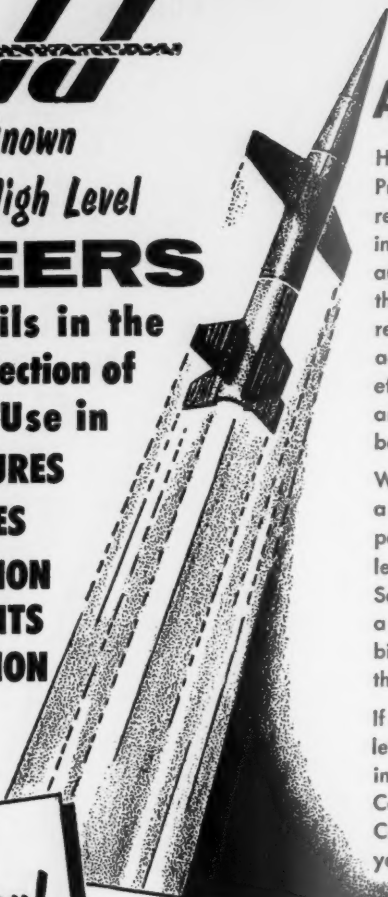
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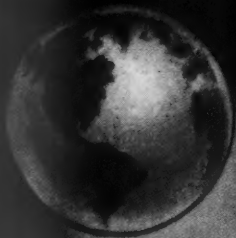
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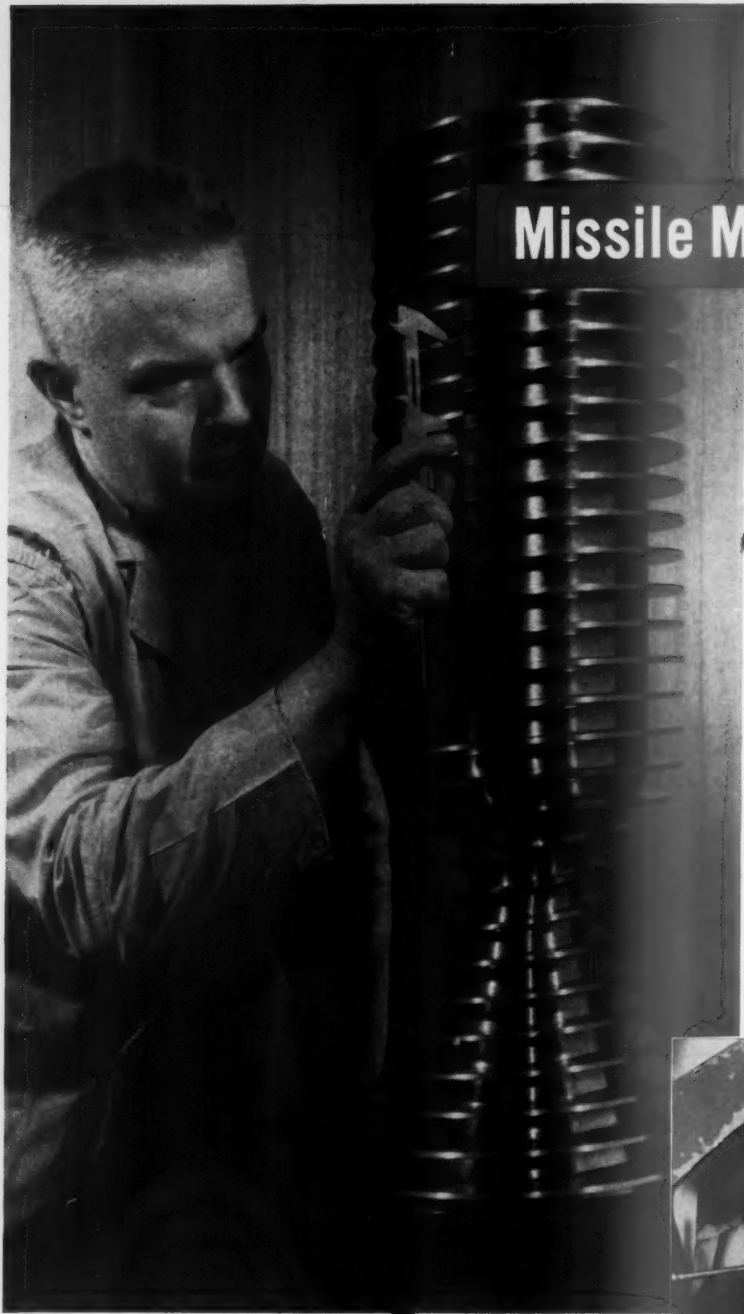
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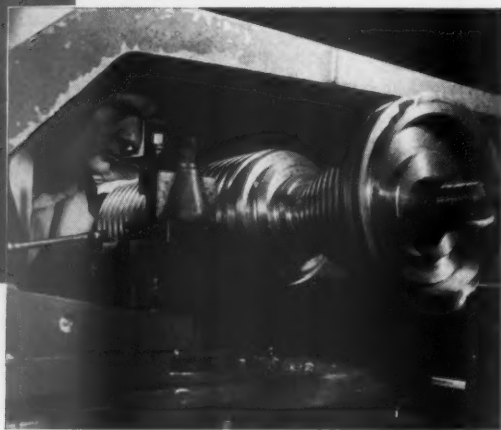


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Some Fundamental Aspects of Ramjet Propulsion

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Marquardt Aircraft Co., Van Nuys, Calif.

Some fundamental characteristics of the ramjet powerplant are discussed in terms of over-all performance, speed and altitude environment and the design and selection of the major ramjet components. A brief discussion of the most formidable problems that are encountered in the design of hypersonic ramjets is also presented.

Introduction

INCREASED interest in the ramjet has developed in very recent years as a result of a steady pressure to increase the speed and altitude capabilities of both airplanes and missiles. Also, several successful applications of this type of powerplant have contributed to this interest.

Considerable information about the ramjet engine exists in the unclassified literature, for example (1-5),² in terms of fundamental propulsion characteristics, environmental envelope and the relative position of the ramjet in the over-all supersonic powerplant spectrum. These aspects of the ramjets will be briefly reviewed. In addition, some of the more detailed considerations facing the ramjet designer regarding the selection of ramjet components will be discussed.

Ramjet Power Cycle

The ramjet incorporates all of the essential features of any air breathing powerplant. Fig. 1 illustrates the several ramjet components and lists the functions of each. The compression phase of the power cycle is accomplished by the forward motion of the engine. A tube of air is captured by the inlet and is slowed down with respect to the powerplant in the supersonic and subsonic sections of the diffuser. In this manner the kinetic energy of the ambient air with respect to the engine is converted into potential energy in the form of pressure. Fuel is then injected into the compressed air and this mixture is burned at essentially constant pressure in the combustion chamber. The expansion phase of the cycle is accomplished by accelerating the air in subsonic and supersonic sections of an exhaust nozzle.

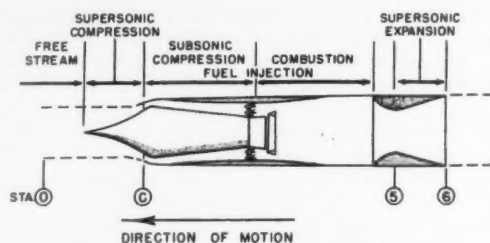


Fig. 1 Components of ramjet power cycle

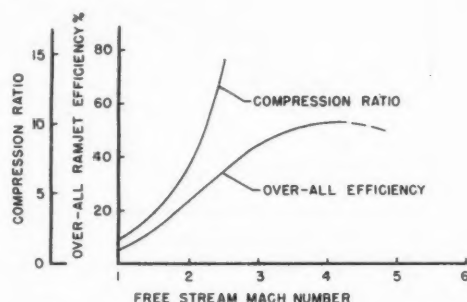


Fig. 2 Ramjet compression ratio and over-all efficiency vs. Mach number

Inasmuch as the ramjet air compression is accomplished by forward motion, it possesses no static thrust and must be brought up to speed by an auxiliary powerplant. Fig. 2 illustrates the influence of forward speed (in terms of Mach number) upon the compression ratio of the ramjet and its over-all efficiency (work accomplished upon the air frame/fuel supplied). The over-all efficiency of the ramjet engine can be seen to be strongly influenced by compression ratio. For example, over-all efficiency at Mach 0.8 is on the order of 3 per cent. This value increases to about 25 per cent at Mach 2.0. Therefore, the ramjet can be expected to have the greatest application in the supersonic regime. The over-all efficiency of a ramjet operating in excess of Mach 4.0 reaches about 50 per cent, which exceeds the efficiencies of all other stationary or air-borne powerplants employing hydrocarbon fuels.

Ramjet Pressure Distribution

A physical understanding of how the various ramjet components contribute to thrust can be gained by inspection of Fig. 3, in which a typical distribution of pressure forces on the internal and external surfaces of a ramjet is illustrated. The

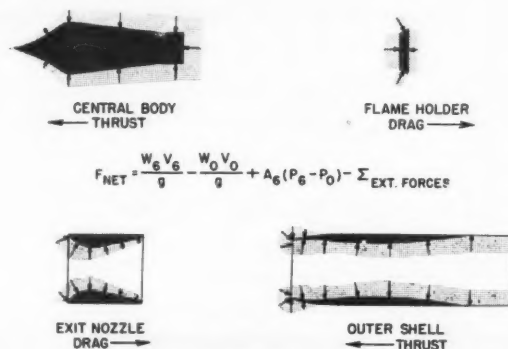


Fig. 3 Typical ramjet pressure distribution

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¹ Supervisor, Aerodynamics Section.

² Numbers in parentheses indicate References at end of paper.

force acting on the most forward portion of the diffuser centerbody produces drag, but the large thrust force acting on the rearward portion results in a large net thrust force. A drag force results from the presence of the flameholder elements and the exit nozzle also contributes to the drag. Although the engine cowl sustains the major portion of the external drag, a high internal pressure more than balances this force and a net thrust upon the cowl results.

Fortunately, it is not necessary to determine the complex distribution of pressure with a ramjet in order to calculate its over-all performance. The equation shown in Fig. 3 expresses the sum of the internal forces on the ramjet as a function of the air flow rate and the entering and issuing jet

velocities. This expression is a form of Newton's third law of motion which states that every force produces an equal and opposite reaction. Consequently, the state of the fluid entering and leaving the ramjet can be examined to determine the net reaction upon the powerplant.

Altitude-Mach Number Envelope

Like all air breathing powerplants, the ramjet is sensitive to its environment. Fig. 4 describes the general range of flight Mach numbers and altitudes that are most favorable for ramjet operation. This graph also describes the physical limitations associated with operating a ramjet significantly outside of these boundaries.

The low compression ratio associated with low Mach number and the resulting low ramjet performance have been previously discussed. Along the high altitude-low Mach number boundary, the reduced combustion chamber pressure starts to reduce the combustion efficiency and to narrow the flame stability limits in terms of fuel-air ratio.

A severe pressure loading is imposed upon the ramjet in the low altitude-high Mach number portion of the envelope which is aggravated, structurally speaking, by increased skin temperatures.

The maximum Mach number at which a gasoline-fueled ramjet can be practically employed has not been established. One of the most difficult problems that gradually presents itself as the Mach number is increased is dissociation of the products of combustion which reduces the temperature ratio across the ramjet.

Performance Comparison With Other Powerplants

There are two parameters that define the basic performance of air-borne powerplants. These are the thrust-to-weight ratio and the specific fuel consumption. Figs. 5 and 6 compare the performance of the ramjet (on the basis of these parameters) with the performances of the rocket, turbojet and afterburning turbojet as a function of Mach number and altitude. These data are necessarily approximate but they do show that the ramjet achieves a thrust-to-weight ratio at Mach 3.0 about midway between the thrust-to-weight ratio of a rocket and an afterburning turbojet. The altitude Mach number variation corresponds to the structural limitation line shown in Fig. 4. Fig. 6 reveals that the ramjet has the lowest fuel consumption of all powerplants at speeds above the Mach 2.0 to 2.5 regime.

The Ideal Ramjet

It is of interest to consider the thrust performance of the ramjet in terms of the limitations of its components. Fig. 7 compares the thrust of ideal and practical ramjets as a function of Mach number. Curve 1 in Fig. 7 represents the performance of a ramjet with infinite heat release in the combustion chamber and zero external drag and internal pressure losses. The thrust coefficient employed for Curve 1 is a rough measure of the thrust-to-weight ratio for comparative purposes at a given altitude and Mach number, since it is based upon the maximum frontal area of the ramjet. Limitation of the combustor heat release to a level that can be obtained with gasoline decreases the performance of the ideal ramjet to that shown in Curve 2. Curve 3 represents a more practical engine sustaining typical drag and total pressure losses, but retaining variable geometry features. The final curve (Curve 4) represents an engine with only fixed geometry components. The sharp slope discontinuities that occur in Fig. 7 are the result of the inlet area reaching the frontal area of the engine combustion chamber upon which the thrust coefficient is based.

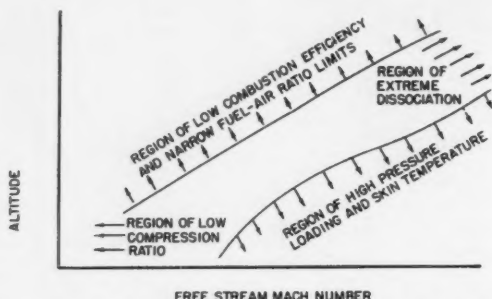


Fig. 4 Typical Mach number-altitude envelope for ramjets

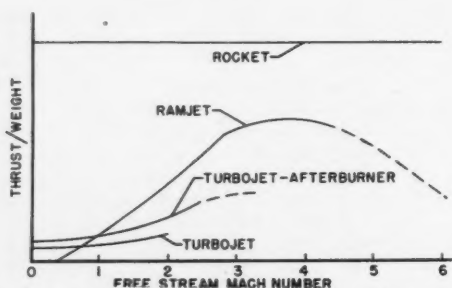


Fig. 5 Thrust-weight ratio comparison of supersonic powerplants

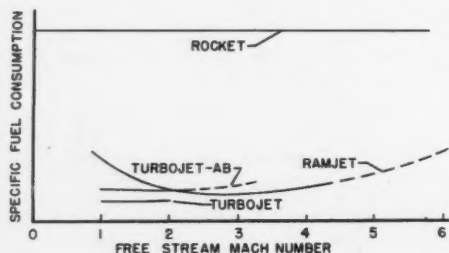


Fig. 6 Fuel consumption comparison of supersonic powerplants

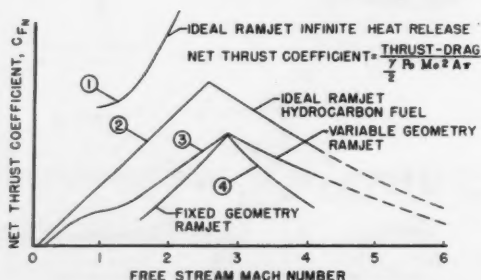


Fig. 7 Ramjet net thrust comparison

Relative Importance of Component Efficiency

Some further understanding of the influence of ramjet component efficiency upon the over-all performance of a ramjet can be gained by reference to Fig. 8. The four major component performance parameters, namely, 1) total pressure recovery, 2) combustion efficiency, 3) nozzle efficiency and 4) external drag, are considered here in terms of their effect upon the over-all thrust of the ramjet. It is apparent that total pressure recovery is by far the most important parameter for ramjets at subsonic and low supersonic Mach numbers. The nozzle efficiency is important at all speeds, and it increases in importance as the speed is increased. Ramjet thrust is relatively insensitive to combustion efficiency at low Mach numbers. However, this parameter becomes of increased importance as the Mach number is increased. All of the component performance parameters become important at very high Mach numbers because of the low level of net thrust coefficient that is attainable (see Fig. 7).

Combustor and Exhaust Nozzle Selection

There are two basic types of ramjet engines that have application to both airplanes and missiles. The first of these is designed to maximize the thrust-to-weight ratio at the expense of fuel consumption and it is intended for application to short and medium range vehicles of the interceptor type. A long range bombardment vehicle, however, would require that fuel consumption be emphasized in order to provide the most efficient over-all system. Fig. 9 illustrates the influence of the combustor design fuel-air ratio (i.e., temperature ratio) and the exit nozzle throat area upon ramjet thrust-to-weight ratio and specific fuel consumption.

In the earlier discussion of engine pressure distribution, it was noted that the exit nozzle contributed a drag force. Consequently, the ramjet thrust-to-weight ratio can be expected to increase as the nozzle throat area is increased. This effect is illustrated by Fig. 9. Correspondingly, the fuel consumption increases as a result of a decrease in the supersonic expansion of the jet. The maximum ramjet fuel economy will occur with an exit nozzle geometry that provides expansion to ambient pressure at the nozzle exit.

Fig. 9 also illustrates the influence of combustor design fuel-air ratio upon the two engine performance parameters. A combustor designed for a high fuel-air ratio will, of course, develop maximum ramjet thrust, and the specific fuel consumption is reduced as the design fuel-air ratio is reduced well below the attainable value. This later improvement results from a reduced jet velocity and the corresponding increase in propulsive efficiency (work accomplished upon air frame/work accomplished upon the engine fluid).

Combining the effects of exit nozzle throat area and combustor fuel-air ratio, the engine having the maximum thrust-to-weight ratio will be composed of a combustor designed for high fuel-air ratio and a maximum nozzle throat size consistent with satisfactory combustor performance. Conversely, the engine having maximum fuel economy will consist of a suppressed fuel-air ratio combustor with a nozzle throat small enough to expand the jet to near ambient pressure at the nozzle exit.

Inlet Considerations

Assuming the combustor-nozzle system to be established on the basis of the previous discussion, consideration can be given to matching a supersonic inlet to this configuration that will provide ramjet performance characteristics consistent with the vehicle objectives. Of primary importance is the range of free stream Mach numbers that are to be considered for utilization of the ramjet. Also, the means by which the ramjet is accelerated into this region must be considered.

The total pressure recovery across a single normal shock is quite satisfactory at low supersonic Mach numbers, but as the

free stream Mach number is increased, oblique shocks must be generated ahead of the normal shock in order to maintain the total pressure recovery at a reasonably high level. Therefore, the maximum Mach number of the specified envelope will influence the degree of supersonic compression (the number of oblique shocks) incorporated into the inlet design. The minimum Mach number will primarily dictate the inlet design compromises that must be made in supersonic compression from the standpoint of external drag.

The air flow requirements of the combustor-nozzle system over the specified range of free stream Mach numbers and altitude conditions must be considered. Fig. 10 illustrates the effects upon ramjet thrust of mismatching the inlet air flow supply and the combustor and nozzle air flow requirement. An insufficient inlet size results in a thrust decrease as the result of internal pressure losses and reduced air flow rate. This type of off-design operation is termed supercritical operation. On the other hand, should too large an inlet be employed, the excess air would be spilled around the inlet and a large drag increase would result. This type of off-design operation is termed subcritical operation. The matching of a supersonic inlet to a ramjet combustor-nozzle system is a

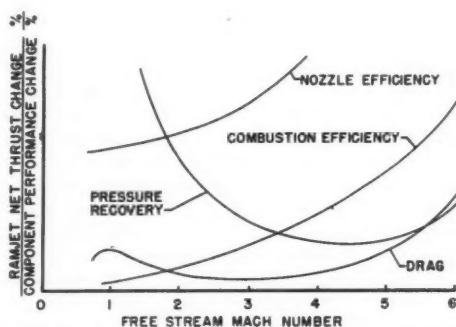


Fig. 8 Effect of component performance upon ramjet net thrust

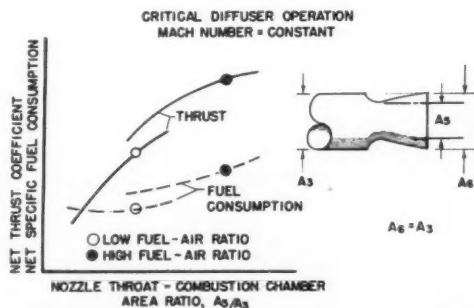


Fig. 9 Typical influence of combustor and exit nozzle design upon ramjet performance

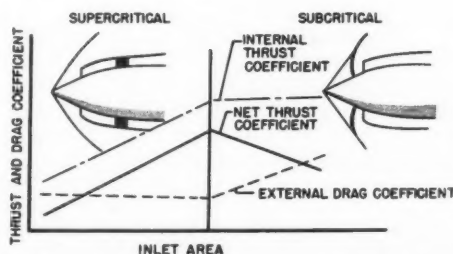


Fig. 10 Typical effect of airflow mismatching upon ramjet net thrust coefficient

simple matter for a single set of Mach number, altitude and ambient temperature conditions. The most difficult problem consists of selecting the inlet design that suffers the least performance penalty at the off-design conditions encountered by most ramjet applications.

Finally, the means by which the ramjet is accelerated can profoundly influence the minimum ramjet operating Mach number and consequently the selection of inlet design. Often a considerable saving in over-all vehicle size, weight and cost can be effected by converting a larger share of the total impulse required for acceleration from a rocket booster to a ramjet, as a result of the more efficient operation of the air breathing powerplant.

Inlet Performance Characteristics

The factors involved in matching a supersonic inlet to the ramjet engine can best be illustrated by considering the basic performance characteristics of supersonic inlets. Figs. 11 and 12 present the total pressure recovery, drag and air flow characteristics of three basic supersonic inlet types as a function of Mach number. The difficulty associated with obtaining high diffuser total pressure recovery with increased Mach number is illustrated by the trend shown in Fig. 11. The decreased total pressure recovery is caused by the increased strength of shocks at high Mach numbers.

Inlet A in Fig. 11 does not incorporate an external (or internal) compression surface, and consequently it has optimum performance (high pressure recovery and low drag) at low supersonic Mach numbers. This configuration provides a constant ratio of free stream tube area to inlet area ($A_0/A_c = 1.0$) because an external compression surface is not present to deflect the approaching supersonic stream. The very low pressure recovery achieved at high free stream Mach numbers results from the large losses associated with a normal shock occurring at a high supersonic Mach number.

Inlet B incorporates a low degree (single cone) of external compression that increases the drag (particularly at lower supersonic Mach numbers), increases the pressure recovery at high Mach numbers and provides a variation in the captured free stream tube area as a function of Mach number. The decrease in the captured tube area with decreasing Mach number results from a steepening of the oblique shock system

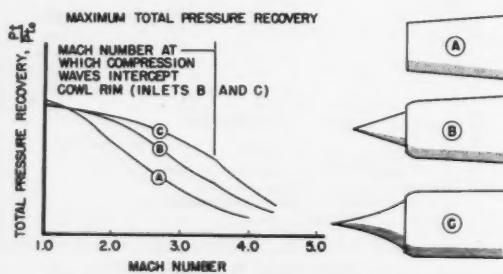


Fig. 11 Performance of typical supersonic inlets

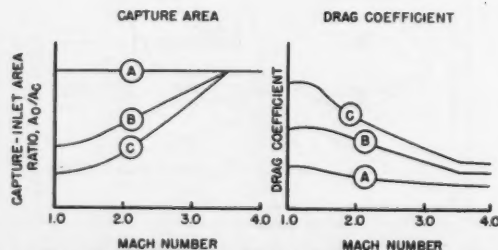


Fig. 12 Performance of typical supersonic inlets

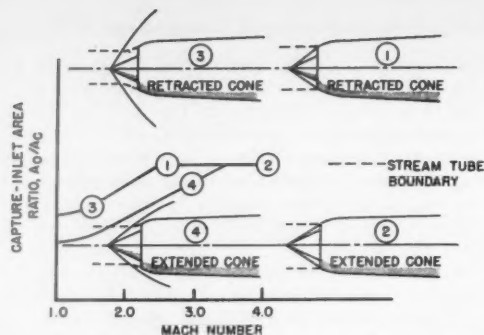


Fig. 13 Typical influence of compression spike position upon capture-inlet area ratio

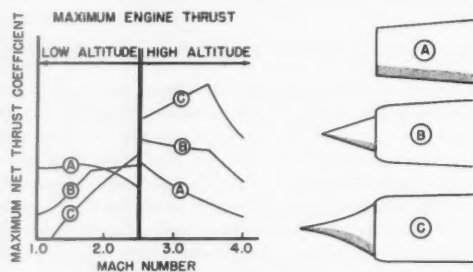


Fig. 14 Comparison of typical ramjet performance characteristics for several inlet designs

which submerges the cowl lip further into the conical flow field.

Inasmuch as the conical flow field streamlines are curved, the captured tube area A_0 is reduced below the projected cowl area A_c . This effect is illustrated in Fig. 13. Fig. 13 also demonstrates the effect upon the capture tube area of moving the compression spike in an axial direction. An upstream movement of the spike produces a reduction in the size of the captured tube if the oblique wave is not intercepted by the cowl.

The improvement in total pressure recovery shown for Inlet B at the higher Mach numbers (see Fig. 11) results from the more efficient supersonic compression achieved by the conical flow field placed ahead of the normal shock. The steeper approaching streamline angles associated with this compression, however, increase the external drag, particularly at the lower Mach numbers.

Inlet C represents an extreme in external supersonic compression. The supersonic stream is compressed by a series of weak shock waves to a very low supersonic inlet Mach number. This design procedure results in the inlet performance characteristics described by Inlet C in Figs. 11 and 12. Similar performance would be exhibited by a perforated inlet incorporating a large degree of internal compression.

Inlet Selection

The influence of general inlet design upon ramjet thrust and fuel consumption characteristics is shown as a function of Mach number in Fig. 14. It is apparent from Fig. 14 that the choice of supersonic inlet geometry has a profound effect upon ramjet thrust performance. Generally speaking, the low drag of Inlet A provides optimum performance in the transonic and low supersonic speed range and the high pressure recovery achieved by the extreme external compression of Inlet C provides a high level of performance at high Mach numbers. A similar comparison can be made between the

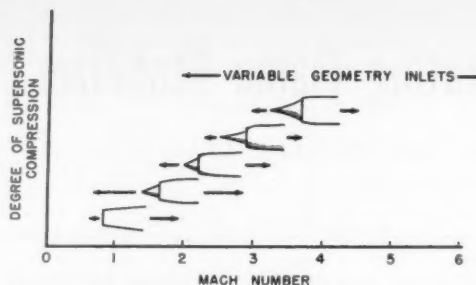


Fig. 15 Effect of Mach number upon degree of supersonic compression

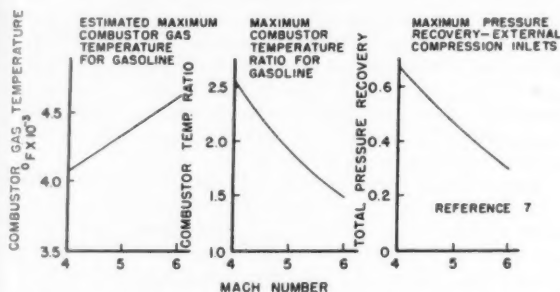


Fig. 16 Some effects of high Mach number upon ramjet operation

inlets on the basis of fuel consumption for both maximum thrust and throttled operation.

Variable Geometry Components

Although the relative ease by which the fixed geometry ramjet can be tailored to various supersonic power requirements makes it a simple and versatile powerplant for application over broad ranges of supersonic Mach numbers, it is apparent that, as the spread in the ramjet operating Mach number is indefinitely increased, the added weight and mechanical complexity associated with a variable geometry inlet is justified.

An attempt to achieve maximum ramjet thrust-to-weight ratio at high supersonic Mach numbers will reveal that the capture area A_0 tends to exceed the maximum frontal area of the engine A_2 upon which thrust coefficient is based (see Fig. 11). Increasing the inlet area beyond this point will have essentially the same effect upon ramjet thrust coefficient (i.e., thrust-to-weight ratio) as reducing the exit throat area A_6 , since some sort of external fairing will probably be required between the inlet and the exit from external drag considerations. Because of this requirement for a reduced nozzle throat area, a variable geometry exit nozzle becomes of special interest for application to ramjets of high thrust-to-weight ratio for high supersonic Mach number application.

A second advantage of using variable geometry components is associated with combining the features of the two types of ramjets discussed under the section on combustor and nozzle design. The use of a variable-throat exit nozzle in conjunction with a combustor that maintains high combustion efficiency over a broad range of fuel-air ratios combines the advantages of high thrust-to-weight ratio and low fuel consumption into a single powerplant.

Ramjet Applications

The choice of inlet design is clearly indicated for a ramjet-powered vehicle restricted to operation at Mach numbers be-

low about 1.7. The pressure recovery, drag and air flow characteristics of the open nose inlet are entirely satisfactory with respect to matching the ramjet powerplant in this speed range. Similarly, a ramjet-propelled vehicle launched from a mother airplane at a high Mach number would obviously employ an inlet of the high compression type. Sandwiched between these two simple examples of ramjet power application are numerous requirements for ramjet powerplant systems designed to operate over a wide range of flight Mach numbers. The inlet-ramjet matching problem becomes complex in the majority of these cases, since an optimum compromise between maximum fuel economy during acceleration and during cruise as well as powerplant weight must be accomplished.

It can be understood that a selection of the optimum ramjet components will depend upon some knowledge of the vehicle mission involved. However, qualitative conclusions can be reached regarding the influence of Mach number envelope upon the inlet selection. Fig. 15 presents several Mach number envelopes that are typical of those that could employ ramjet propulsion and the corresponding degree of supersonic inlet compression to be employed in the inlet design.

The Hypersonic Ramjet

When discussing powerplants, it is always interesting to speculate: Where do we go from here? Fig. 16 describes some of the more formidable problems that are encountered by ramjets as they penetrate into the hypersonic Mach number region.

An estimate of the combustion gas temperature that is imposed upon the combustor components of a hypersonic ramjet is presented in Fig. 16. Since air-cooled ramjets operating at gas temperatures below 4000 F are currently exposed to skin temperatures near the structural temperature limits of metallic materials (6), it is probable that some sort of special cooling techniques must be employed.

A decrease in temperature ratio across the combustor suppresses the ramjet thrust level at high Mach numbers. This decrease (see Fig. 16) results from two factors; namely, a reduced temperature rise due to dissociation of the combustion products and an increased inlet total temperature.

A severe limit exists upon the amount of supersonic compression that can be accomplished on an external surface (7). This results in the maximum achievable pressure recovery for external compression inlets shown in Fig. 16. The most obvious method of exceeding this limit is to resort to variable geometry inlet components employing internal supersonic compression.

References

- 1 Harned, M. S., "The Application of the Ramjet to Aircraft Propulsion," ASME/ARS Paper 71-52, Nov. 1952.
- 2 Marsh, B. W., and Sears, G. A., "Introduction to the Analysis of Supersonic Ramjet Powerplants," JET PROPULSION, May-June 1954, pp. 155-161.
- 3 Avery, William H., "Twenty-Five Years of Ramjet Development," JET PROPULSION, Nov. 1955, pp. 604-614.
- 4 Anderton, D. A., "Talos Integrates Terror Frame, Ramjet," Aviation Week, vol. 64, Jan. 16, 1956, pp. 37-41.
- 5 Thomas, A. N., "How to Match Ramjet Inlets and Performance," Aviation Age, vol. 25, Feb. 1956, pp. 24-31.
- 6 Unterberg, W., "Is There a Thermal Barrier for Supersonic Ramjet Tailpipes?" JET PROPULSION (to appear).
- 7 Connors, James F., and Meyer, Rudolph C., "Design Criteria for Axisymmetric and Two-Dimensional Supersonic Inlets and Exits," NACA TN 3589, Jan. 1956.

Preliminary Evaluation of a Rotating Flame Stabilizer¹

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The feasibility of rotating a bluff flameholder as a means of increasing volumetric heat-release rates in high-output combustion chambers has been investigated. A cylindrical flameholder with its longitudinal axis normal to the flow of combustible gases was rotated rapidly about a transverse axis parallel to the flow. This rotation resulted in the generation of flame front at higher rates than when the flameholder remained stationary, and volumetric heat-release rates were correspondingly increased. Rotation of the flameholder, however, also tends to reduce the stability limits. For any one tailpipe length, the combustion efficiency increased with increasing rate of rotation. This increase tended to be greater the lower the inlet gas velocity. The power required to overcome the rotational drag was calculated to be usually less than the losses due to wall friction or axial drag of the flameholder. Possible applications of rotating flameholders are discussed.

Introduction

THERE is a continuing demand by jet engine designers and others for combustion chambers with very high volumetric heat-release rates. One of the most common means of attaining high volumetric heat-release rates is by means of a flame stabilized in the wake of a stationary bluff object mounted with its axis normal to the flow of high velocity combustible gases that are entering the combustion chamber. Combustion is completed in such a chamber by the propagation of the flame from the low velocity region near the flameholder wake, either to the chamber wall or to the intersection of a flame propagating from an adjacent flameholder. The propagation of the flame is usually aided by turbulence in the approach flow and generated by the flame. Such a system is shown schematically in Fig. 1(a) where a flame is stabilized in the wake of a cylindrical rod mounted with its axis normal to the flow in a combustion chamber of circular cross section.

Heat-release rates per unit volume in this chamber can be increased without increasing the inlet velocity or changing the air-fuel mixture by adding more stabilizers. In instances where the area blocked by the stabilizer array is relatively small, the length of the combustion chamber required for complete combustion may thereby be reduced, the only significant price being the increased pressure drop across the stabilizers and a corresponding reduction in over-all efficiency. In many practical situations, however, for example with most ramjet and turbojet afterburner stabilizers, the stabilizer array blocks 25 per cent or more of the combustion chamber cross section and the stabilizer characteristic dimension has been made relatively large to insure wide stability limits.

Under these conditions, a further increase in number of stabilizer elements would often result in prohibitively large stabilizer blocked areas with attendant substantially

decreased stability limits and more than proportional increases in stabilizer drag.

Another means proposed by the authors for reducing the required length of the combustion chamber and for obtaining higher volumetric heat release rates is to rotate the stabilizer about its transverse axis oriented parallel to the flow. Such rotation, if it is at a speed high enough so that the outer tips of the stabilizer move at a tangential velocity of the same order as that of the inlet gases, should not only result in the generation of flame surface at substantially higher rates than with the flameholder stationary, but the location of the newly generated flame front would be constantly moving so that propagation of the flame for shorter distances would be necessary for completion of combustion.

Shown schematically in Fig. 1(b) is the flame surface that might be generated by rotating the cylindrical rod in the circular chamber in such a way that the flameholder makes one complete revolution while the inlet gases flow a distance of one chamber diameter. Comparison of Figs. 1(a) and 1(b) shows how rotation of the stabilizer might be expected to shorten the combustion chamber length. As the rate of rotation of the stabilizer increases, other things remaining equal, the greater should be the rate of generation of flame front. Thus the greater the rate of rotation, the shorter should be the combustion chamber length that is required for essentially complete combustion. On the other hand, axial pressure drop due to presence of the rod should not change greatly with changes in the rate of rotation. Additional energy will, of course, be required for stabilizer rotation.

As far as the combustion is concerned a similar effect should be obtained by rotation of flow with the stabilizer remaining stationary. However, since the energy required to rotate the gases would probably be greater than that needed to rotate the stabilizer, and the measurement and control of the rotational gas velocity would be more difficult than that of the stabilizer, only the system with the rotating stabilizer was investigated. Schwartz (1),⁵ in a preliminary investigation of combustion with rotational flow in an annular combustion chamber and an annular stabilizer, found some effect of rotation on the combustion.

Experimental Program

A preliminary experimental study has been conducted to evaluate the performance of a simple rotating stabilizer as a means of increasing volumetric heat release rates in high-output combustion chambers. This experimental study consisted of three parts. The first part involved determination of the effect of stabilizer rotation on the stability limits of the combustion chamber. In the second part, flames propagating from the rotating stabilizer were observed visually and were investigated by photographic means. Both time exposures and high speed motion pictures were taken, and the flames were also observed through a stroboscopic viewer. In the third part of the program, the combustion efficiency across the chamber was measured for various inlet flow conditions and rates of rotation of the stabilizer. In addition, consideration has been given to the energy requirements for rotation of the stabilizer.

A schematic diagram of the apparatus used in the experimental study is shown in Fig. 2. Air was supplied from an oil-free compressor capable of delivering a maximum of

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⁵ Numbers in parentheses indicate References at end of paper.

about 0.05 lb/sec of air at a pressure of approximately 60 psi. The compressed air was dried by passage through a separator for removal of entrained water and through a

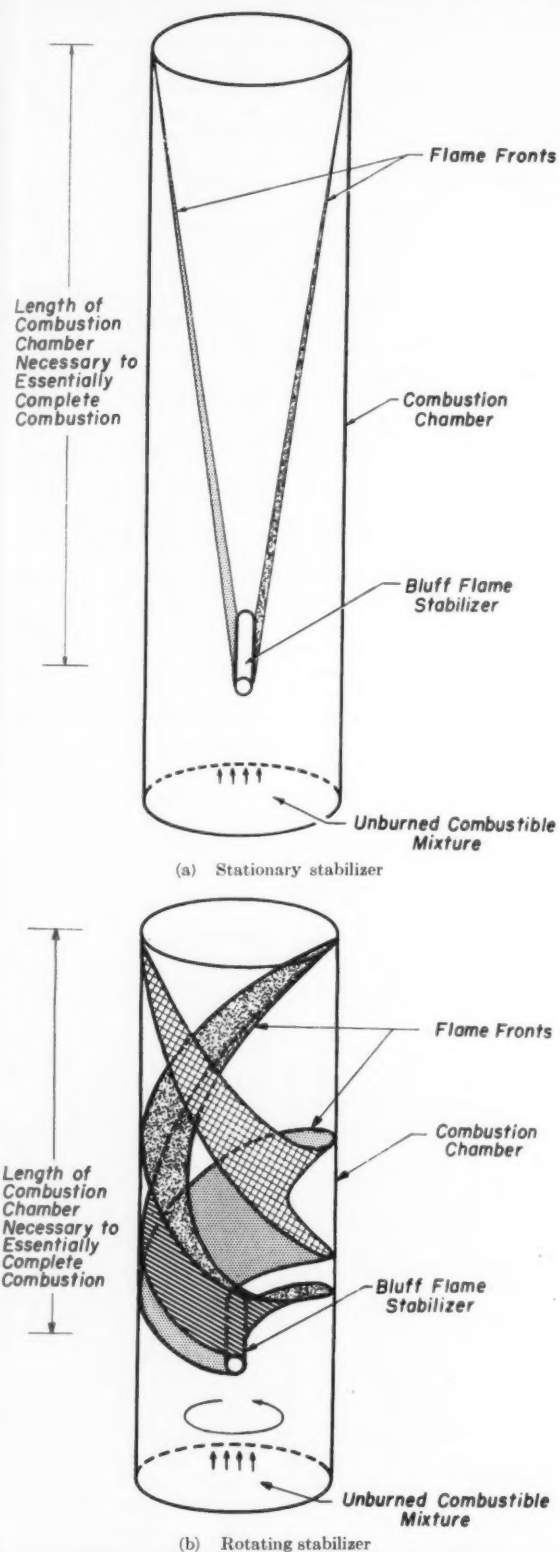


Fig. 1 Schematic comparison of flames generated with stationary and rotating stabilizer

silica gel bed for absorption of water vapor. The air was then metered by a rotameter and passed through a control valve which regulated the flow rate and reduced the pressure. From the control valve the air entered an inspirator, as the primary stream, where it pumped in low pressure natural gas (about 88 per cent methane) and the two streams were thoroughly mixed.

The natural gas obtained from the city main was metered by a rotameter. It then passed through a control valve and on to the inspirator.

The air-fuel mixture proceeded from the inspirator through a heat exchanger, used for temperature regulation, and into the calming section. In the calming section the gases passed through a perforated plate and then through five 200-mesh screens inserted to smooth the flow and eliminate large velocity fluctuations. The gases then passed through a 25:1 contraction-ratio nozzle, which reduced the turbulence intensity to less than one per cent, and finally into the combustion chamber. The combustion products were vented to an exhaust stack.

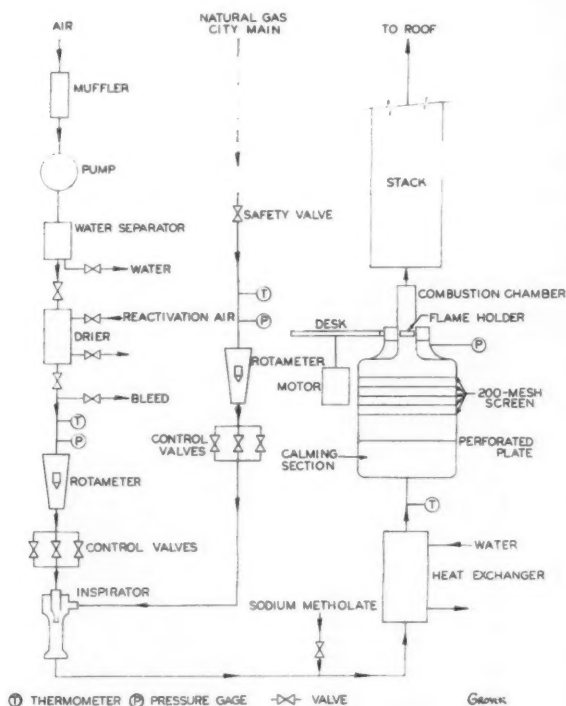


Fig. 2 Schematic diagram of combustion apparatus

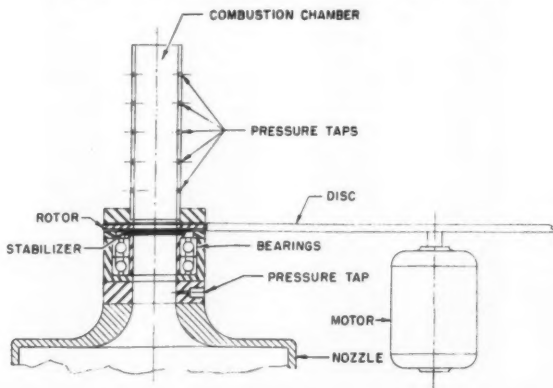


Fig. 3 Schematic drawing showing details of combustion chamber and rotating flame stabilizer

Details of the combustion chamber and rotating flame stabilizer are shown in Fig. 3. The combustible gases entered the 1.5-in.-diam vertical combustion chamber through the converging nozzle and flowed past the stabilizer. The stabilizer was a 0.2-in.-diam rod oriented normal to the flow, and was firmly attached to a section of the wall that was free to rotate. This section of the chamber was mounted on ball bearings and was separated from the remaining stationary portion of the chamber. A disc mounted on an electric motor was in contact with the projecting rotor of the movable part of the chamber and was used to rotate the stabilizer. Two different motors were employed. One was a constant-speed induction motor which rotated the stabilizer at 7800 rpm. The other was a motor that could be run at variable speed. Downstream of the rotating section of the chamber was a length of glass tube.

Two photographs of flames stabilized in this chamber are shown in Fig. 4. The photographs were taken with an exposure time of 0.1 sec. Both are stoichiometric natural gas-air flames, and in both the approach flow velocity was 20 fps. In Fig. 4(a) the 0.2-in.-diam rod stabilizer was held stationary with its axis normal to the plane of the picture. This flame propagated downstream from the stabilizer in the usual manner. Since the flame does not spread across the entire chamber it may be concluded that combustion in the chamber was incomplete. The flame in Fig. 4(b) was with the same 0.2-in.-diam rod stabilizer rotating at 7800 rpm. This flame does not extend as far downstream as the Fig. 4(a) flame. It would thus appear that combustion was more nearly completed within the chamber when the stabilizer was rotated.



(a) Stationary stabilizer (b) Rotating stabilizer (7800 rpm)
Fig. 4 Photographs of stoichiometric natural gas-air flames—velocity, 20 fps; stabilizer, 0.2-in. rod; chamber, 1.5-in. glass tube

Results

A complete stability limit curve was obtained both for the stabilizer in a stationary position and for it rotating at 7800 rpm. These curves are shown in Fig. 5, where blow-off velocity is plotted vs. reduced oxidant fraction, O_G .⁶ The stability limits were obtained using a 2-in. tailpipe. The use of this short tailpipe greatly reduced the effects of resonance and rough burning on the stability of the flame. Thus the differences in stability result only from stabilizer rotation.

At low combustion chamber inlet velocities (20 to 60 fps) where the tangential velocity of the stabilizer tips (50 fps) is of the same order as the flow velocity, the stability is markedly decreased when the stabilizer is rotated. There is even a curving in of the limits at the lower velocities.

At these velocities the velocity component due to rotation is a large fraction of the total, and a decrease in stability would be expected when the stabilizer is rotated. However, the curving-in of the stability limits at the low velocities was unexpected and the reason for this has not yet been determined. Rotation of the stabilizer undoubtedly produces a superimposed circulation of gases from the axis of rotation out toward the stabilizer tips. Since this centrifugal pumping action would be expected to be relatively more important at low inlet velocities, it may in some way account for the unexpectedly large reduction in flame stability of the rotating stabilizer at these low velocities.

In the middle velocity range (60 to 250 fps) the stability was only very slightly decreased when the stabilizer was rotated. This might have been expected since as the axial velocity is increased the rotational velocity of the stabilizer becomes a smaller fraction of the total. The peak blow-off velocity is decreased from 430 fps for the stationary stabilizer to 300 fps for the stabilizer rotating at 7800 rpm. This sig-

$$O_G = \frac{\text{air/fuel}}{\text{air/fuel} + (\text{air/fuel})_{\text{stoichiometric}}}$$

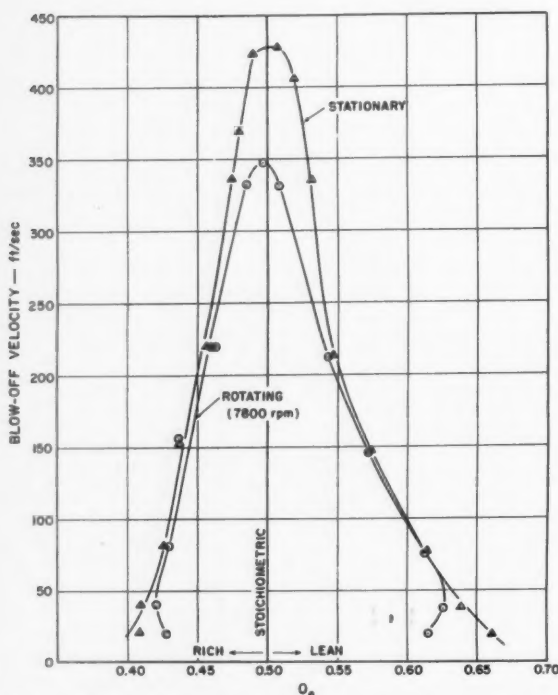


Fig. 5 Effect of rotation of stabilizer on stability limits—natural gas-air mixture, 1.5-in.-diam chamber, 0.2-in. rod stabilizer 2 in. from chamber exit

nificant decrease was unexpected since at these high velocities the added rotational velocity is only a very small fraction of the axial flow velocity.

Of course, the rotation of the stabilizer causes the flow patterns in the vicinity of the stabilizer to be changed so that the flow of reactants and combustion products near the stabilizer are somewhat different than with the stationary stabilizer. These changes may modify to some extent the mechanism of flame stabilization and thus may cause the difference in flame stabilization when the stabilizer is rotated.

Stability limits were also obtained as a function of speed of rotation of the stabilizer for axial inlet flow velocities of 25 and 75 fps. A 6-in. tailpipe was employed for these measurements and the results are shown in Fig. 6. Stability is observed to decrease with increasing rate of rotation at both flow velocities, with the decrease being more pronounced at a velocity of 25 than at 75 fps. At the high rates of rotation the stability limits are narrower at 25 fps. These results agree with those of Fig. 5 and, except for the stability being poorer for the inlet velocity of 25 fps at the high rates of rotation, they are much as expected.

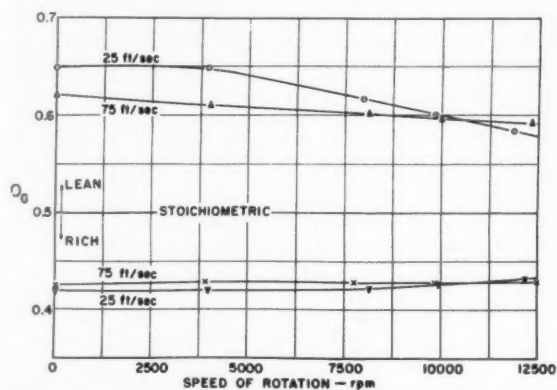


Fig. 6 Effect of speed of stabilizer rotation on stability limits—natural gas-air mixture, 1.5-in.-diam chamber, 0.2-in. rod stabilizer 6 in. from chamber exit

The second phase of this investigation was a visual and photographic study of the effect of rotating the stabilizer. Time-exposure photographs in both color and black-and-white were obtained for several conditions of air-fuel ratio, flow velocity, and speed of rotation. Two of these photographs are shown in Fig. 4. Although these pictures indicate that rotation of the stabilizer results in a shortening of the flame, changes in combustion efficiency could not be measured quantitatively from the pictures.

To determine the appearance of the instantaneous flame front generated by the rotating stabilizer, high speed motion pictures of the flame were obtained. Pictures at a rate of 64 frames per sec were taken at start up, and pictures at a rate of about 1000 frames per sec were taken for the stabilizer rotating at 7800 rpm. Two series of pictures taken at 1000 frames per sec of a stoichiometric natural gas-air flame with an inlet flow velocity of 25 fps and the stabilizer rotating at 7800 rpm are shown in Fig. 7. In order to obtain sufficient illumination, it was necessary to brighten the flame by addition to the air-fuel mixture of an atomized solution of sodium methylate in alcohol. Both of these series of pictures show the generation and propagation of the twisted flame when the stabilizer is rotated. The stabilizer is at the bottom of the frame and rotates about 47 deg between frames. By viewing the pictures in sequence the new twists are seen to be generated and propagate down stream.

The flame above the rotating stabilizer was also observed through a stroboscopic viewer. Through this viewer the flame and stabilizer could be made to appear stationary, and a flame

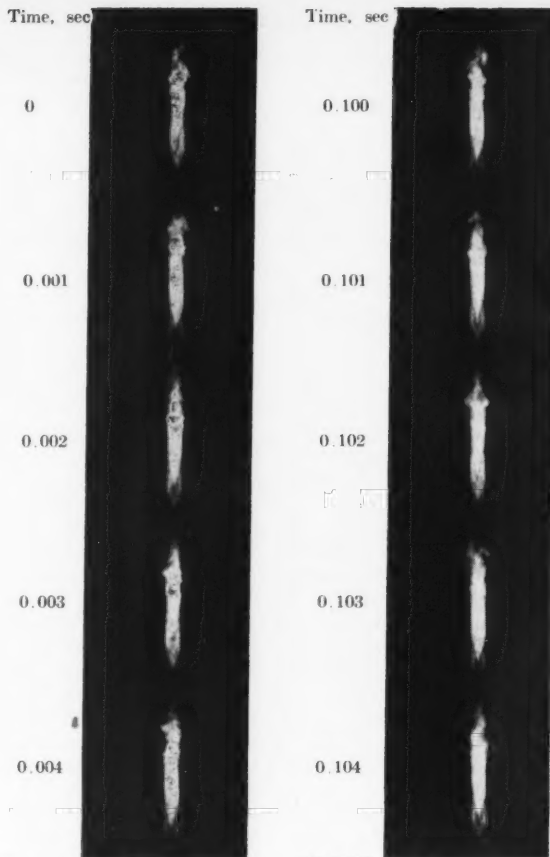


Fig. 7 High speed motion picture of stoichiometric natural gas-air flame—velocity, 25 fps; stabilizer, 0.2-in. rod; chamber, 1.5-in. glass tube; speed of rotation, 7800 rpm; framing rate, 1000 frames/sec

similar to that obtained in the high speed pictures was observed. These visual observations further confirmed that rotation of the stabilizer results in a twisted flame front essentially as anticipated.

The third phase of this investigation was a quantitative study of the effect of stabilizer rotation on the combustion efficiency of the 6-in. chamber. The combustion efficiency η was defined as

$$\eta = \frac{\Delta P - \Delta P_{F,D}}{\Delta P_{Th}} \quad [1]$$

where ΔP is the measured pressure drop across the combustion chamber that results from combustion, friction and drag; $\Delta P_{F,D}$ is the pressure drop due to wall friction and drag of the stabilizer; and ΔP_{Th} is the theoretical pressure drop resulting from complete combustion for the particular air-fuel mixture and inlet flow velocity employed; η was determined as a function of speed of rotation for several flow velocities.

Although this method of determining the combustion efficiency is only an approximation, it is very simple and straightforward and is believed to be adequate for the present comparative purposes. The results of these measurements are shown in Fig. 8 where combustion efficiency is plotted vs. speed of rotation. The results are also given in Table 1. For a flow velocity of 20 fps the efficiency increases from 50 per cent for the stationary stabilizer to essentially complete combustion at 9000 rpm. For a flow velocity of 25 fps the efficiency increases from 40 per cent for the stationary stabilizer to essentially complete combustion at 11,000 rpm. For a flow velocity of 50 fps the combustion efficiency increases

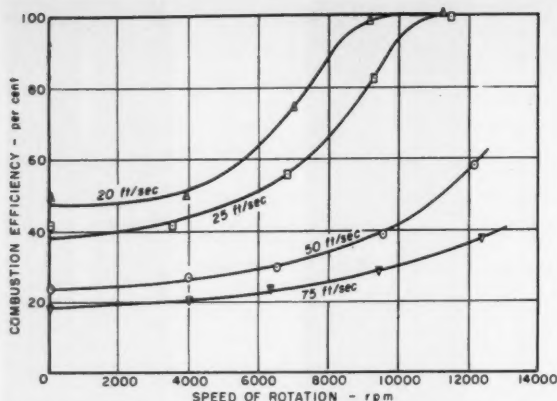


Fig. 8 Combustion efficiency vs. speed of rotation for various approach stream velocities—0.2-in. rod stabilizer 6 in. from chamber exit

from 25 per cent for the stationary stabilizer to 60 per cent at 12,000 rpm. For a flow velocity of 75 fps the efficiency increases from 18 per cent for the stationary stabilizer to 40 per cent at 13,000 rpm.

At all of these flow velocities there is very little improvement in combustion efficiency for speeds of rotation of less than 4000 rpm. As would be expected, for a given increase in rate of stabilizer rotation the improvement in combustion efficiency is greatest at the lowest flow velocities. These results show that the volumetric heat release rate of a high-output combustion chamber can be markedly increased by rotation of the flame stabilizer.

One important factor that must be considered in evaluating the utility of a rotating stabilizer is the power required for stabilizer rotation. The minimum power required to rotate the stabilizer is that needed to overcome the rotational drag of the stabilizer, with additional power being required to overcome any mechanical friction associated with rotation. For a cylinder rotating about its transverse axis the drag is given by

$$\text{drag} = \frac{C_D \rho \pi \omega^2 L^3}{6} \quad [2]$$

and the power need to overcome that drag is given by

$$\text{power} = \frac{C_D \rho \pi \omega^3 L^4}{8} = \frac{C_D \rho V_T^3 L}{8} \quad [3]$$

where C_D is the drag coefficient, which is near unity for cold flow over the range of Reynolds numbers of interest (1); d is the diameter of the rod; ρ is the density of the air-fuel mixture; ω is the angular rate of rotation of the rod in revolutions per unit time; L is the length of the cylinder; and V_T is the tangential velocity at the tip of the rod. For a 0.2-in.-diam cylinder rotating in a 1.5-in. tube at 7800 rpm, the minimum power required is only 0.081 ft-lb/sec.

The axial drag force on a cylinder is given by

$$\text{drag}_{\text{axial}} = \frac{C_D \rho L V_i^2}{2} \quad [4]$$

and the power loss from this drag is given by

$$\text{power} = \frac{C_D \rho L V_i^3}{2} \quad [5]$$

where V_i is the inlet gas velocity. By dividing Equation [3] by Equation [5] the ratio of the rotational power to the axial drag power is given as

$$\frac{\text{power}_{\text{rotational}}}{\text{power}_{\text{axial drag}}} = \frac{1}{4} \left(\frac{V_T}{V_i} \right)^3 \quad [6]$$

Thus when the inlet flow velocity is equal to the tip speed of the rod, the power losses due to axial drag are four times the power required to rotate the cylinder.

The pressure drop ΔP due to wall friction in a tube is given by the Fanning equation (2)

$$\Delta P_{\text{wall friction}} = \frac{2fXV_i^2\rho}{D} \quad [7]$$

and the corresponding power loss is given by

$$\text{power}_{\text{wall friction}} = \Delta P \cdot \frac{\pi D^2}{4} \cdot V_i = \frac{\pi f X V_i^3 \rho D}{2} \quad [8]$$

where f is the friction factor and is a function of the Reynolds number; X is the length of the tube; and D is the diameter of the tube. For cold-flow conditions with a velocity of 50 fps in a 6-in. length of 1.5-in.-diam tube the power loss due to wall friction is 0.427 ft lb/sec, or about five times the power required to rotate the 0.2-in.-diam cylinder at 7800 rpm. When burning takes place in the tube the power loss is multiplied by the density ratio of unburned to burned gases, ρ_u/ρ_b , over the portion of the tube wall that the burned gases are in contact with. Since ρ_u/ρ_b is usually about 8, power loss due to wall friction will often be somewhat higher than is indicated by this equation. The total heat release rate ΔH from the combustion reaction is given by

$$\Delta H = \frac{Q \rho \pi D^2 V_i}{4} \quad [9]$$

where Q is the heat of combustion per pound of air-fuel mixture. For a stoichiometric mixture of methane-air flowing through a 1.5-in. tube with a velocity of 50 fps, this heat is 43,600 ft lb/sec, which is several orders of magnitude greater than the power required to rotate the stabilizer.

The power required to rotate a 0.2-in. rod in a 6-in.-long, 1.5-in.-diam combustion chamber, the power loss due to axial drag of the rod, the power loss due to cold-flow wall friction, and the heat release rate are given in Table 2 for inlet velocities of 50, 100 and 200 fps and rates of rotation of 7800, 15,000 and 30,000 rpm. These results show that when the speed of the stabilizer does not exceed the inlet flow velocity, the power required to rotate the stabilizer is much less than the axial drag and wall friction losses. Even at the relatively higher rates of rotation the rotational power requirements are not excessive.

From the results of Tables 1 and 2 the power requirements for reducing the combustion chamber length to one-half by rotating the stabilizer can be compared with reducing it to one-half by doubling the number of stabilizers. With an inlet velocity of 50 fps, rotation of the stabilizer at 11,000 rpm increases the combustion efficiency for the 6-in. chamber from 24 to 50 per cent. Assuming the combustion efficiency is linear with chamber length, essentially complete combus-

Table 1 Combustion efficiency as a function of speed of stabilizer rotation for stoichiometric natural gas-air flame in 1.5-in.-diam chamber with 0.2-in. rod stabilizer 6 in. from chamber exit

Speed of Rotation, rpm	Combustion efficiency, %			
	Inlet flow velocity, fps			
	20	25	50	75
0	48	38	24	18
2000	49	46	25	19
4000	52	45	27	21
6000	75	52	30	23
8000	87	66	35	26
10000	100	94	43	30
12000	100	100	55	36

Table 2 Power required to rotate a 0.2-in. rod in a 6-in.-long 1.5-in.-diam combustion chamber, power loss due to axial drag of cylinder, power loss due to wall friction and heat release rate

Rate of rotation, rpm	7,800	7,800	7,800	15,000	15,000	15,000	30,000	30,000	30,000
Inlet velocity, fps	50	100	200	50	100	200	50	100	200
Power, ft lb/sec									
Rotational drag	0.081	0.081	0.081	0.576	0.576	0.576	4.62	4.62	4.62
Axial drag	0.301	2.41	19.3	0.301	2.41	19.3	0.301	2.41	19.3
Cold-flow wall friction	0.427	3.42	27.3	0.427	3.42	27.3	0.427	3.42	27.3
Heat release rate	43,600	87,200	174,400	43,600	87,200	174,400	43,600	87,200	174,400

tion could be obtained in a 12-in. chamber, either by rotating the stabilizer at 11,000 rpm or by using two stabilizers. From Table 2 the power losses for the rotating stabilizer would be 0.226 ft lb/sec to rotate the stabilizer, 0.301 ft lb/sec from axial drag and 0.854 ft lb/sec from wall friction for a total of 1.381 ft lb/sec. The losses for the two stationary stabilizers would be 0.602 ft lb/sec from axial drag and 0.854 ft lb/sec from wall friction for a total of 1.455 ft lb/sec.

Thus the additional power required to attain essentially complete combustion by rotating the stabilizer is no greater than the power loss due to the use of an additional stabilizer to attain essentially complete combustion. However, since the use of an additional stabilizer is usually simpler than is rotating the stabilizer, the use of a rotating stabilizer would probably be recommended when the blocked area of the stabilizer does not have a large effect on stability or performance.

Conclusions and Recommendations

It is concluded from this experimental study that rotation of the flame stabilizer results in a twisted flame front. This twisting or folding of the flame front reduces the axial length of the combustion chamber necessary for completion of combustion. Thus, other things being equal, the volumetric combustion efficiency of a high-output combustion chamber can be substantially increased by rotation of the flame stabilizer, and the combustion efficiency can be controlled by changing the rate of stabilizer rotation.

There is some loss of stability as a result of rotation of the stabilizer. However, the reduction of stability is mainly a decrease of peak blow-off velocity, and the effect of rotation vs. stability is only very slight for other conditions.

The power required to overcome rotational drag of the

stabilizer was determined to be usually less than the power losses caused by wall friction or axial drag, and to be several orders of magnitude less than the heat release rate from combustion. Thus the power requirements are not excessive and should not preclude its practical application. However, when the chamber blockage caused by the stabilizer is not important, it would appear that the simplicity of using additional stabilizers would usually make this the preferable method.

A rotating stabilizer might be well suited for use in a turbojet afterburner where a shaft rotating at high speed is directly available and where control of combustion efficiency might be advantageous in avoiding flameout of the tailpipe burner. At lower combustion efficiencies associated with lower rates of rotation the flame would tend to be more stable than at high combustion efficiencies. Also any reduction in tailpipe length attainable with the rotating stabilizer would result in a lighter and more efficient motor. A rotating flame stabilizer might also find application in certain industrial burners where it is necessary both to vary and control the combustion efficiency.

Based on this preliminary evaluation, it appears that further work directed toward determination of the feasibility of employing a rotating stabilizer in specific applications would be worth while.

References

- 1 Schwartz, J. R., "A Preliminary Investigation of Combustion with Rotating Flow in an Annular Combustion Chamber," NACA RM L51E25a, Sept. 1951.
- 2 Prandtl, L., and Tietjens, O. G., "Applied Hydro- and Aeromechanics," McGraw-Hill, New York, 1934, p. 97.
- 3 Walker, W. H., Lewis, W. K., McAdams, W. H., and Gilliland, E. R., "Principles of Chemical Engineering," McGraw-Hill, New York, 3rd edit., 1937, p. 77.

Just a reminder:

ARS Semi-Annual Meeting

June 10-13, 1957

San Francisco at the St. Francis Hotel

The ARS Semi-Annual Meeting, to be held at the St. Francis Hotel in San Francisco, June 10-13, 1957, will feature technical sessions on instrumentation, guidance, combustion, solid rockets, liquid rockets, hypervelocity flight and space flight.

Included in the program will be a luncheon, a banquet and a field trip to NACA's Ames Aeronautical Laboratory. The luncheon speaker will be Dan Kimball, president of Aerojet-General Corp. and former Secretary of the Navy.

Running concurrently with the meeting will be the ASME Semi-Annual Meeting at the Sheraton-Palace Hotel. Sessions on aircraft maintenance and aircraft mechanisms will be held by ASME.

See May JET PROPULSION for full program listings.

Application of the Rocket Jet to Mining and Quarrying

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Military needs have focused attention on application of the rocket principle to weapons and aircraft for purposes of propulsion. Since World War II, however, there has been a parallel program concerned with industrial applications of the very same principle. As a result of this work, rocket flames are now used for the drilling of very hard low-grade iron ores (taconite), the production of primary blast holes in crushed stone quarries, and for channeling, shaping, and finishing operations in the dimension stone industry. Finally, rocket flames may be used for the flame blasting or cleaning of structural shapes.

There are basic differences between the design of rocket equipment for military use and for industrial purposes. Military specifications usually require maximum thrust and minimum weight. Rocket equipment for industrial use is, however, generally designed for low-cost operation over extended periods with minimum maintenance. Furthermore, flame characteristics must be tailored to suit the needs of specific applications. In this respect, studies involving industrial applications of the rocket principle have been centered on the flame itself. Flame geometry, heat transfer, velocity decay, and supersonic-jet noise profile have proved to be factors of paramount importance.

This paper will trace the industrial development of accepted commercial processes involving the rocket principle in terms of theory and actual applications. Discussion will also center on problems of equipment design and methods for prolonging the life expectancy of equipment

Introduction

MILITARY needs have focused attention on application of the rocket principle to weapons and aircraft as a means of propulsion. Since World War II, there has been a parallel program concerned with industrial applications of the same principle—primarily in the mining and quarrying industries. As a result of this program and as indicated in Fig. 1, a rocket-type flame is now being used to produce

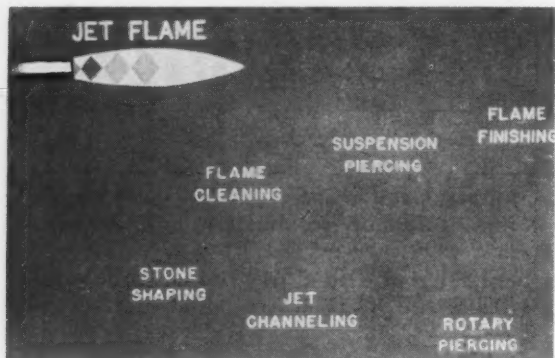


Fig. 1 Jet flame applications

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blastholes in iron bearing taconites. The same type flame is also being applied to the flame cleaning of steel and other structural materials. More recently, the rocket flame is being used for making channels in dimension stone quarries. In the same industry, rocket flames are being applied to the shaping and finishing of various stones.

The development of rocket processes for mining and quarrying involves a phenomenon known as "spalling." Spalling is the flaking or cracking of thin layers of stone due to thermally induced expansion of the surface. The pneumatic wash of the flame gases removes the loosened material, thus exposing a fresh surface to the flame. This paper briefly outlines basic requirements for industrial application of the various rocket flame processes.

Mining and Quarrying Industry Applications

Rotary Piercing

This country's largest reserve of domestic iron ore consists of iron bearing ore formations called taconite. These formations are found principally in the Mesabi Range of northern Minnesota and throughout the northern Michigan peninsula, where the formations are known as jaspers. During the past half century, several attempts have been made to mine this ore. One of many reasons which caused the failure of these attempts is the extreme hardness of the ore. Drilling operations were slow and expensive. Taconite, possessing a hardness capable of scratching glass, could not be drilled economically with the equipment available at that time. Other technical problems of comparable magnitude in the various phases of mining prevented commercial exploitation of this supply of iron ore.

The inability to drill blastholes economically for mining purposes and then to produce an economical concentrate was not considered serious until World War II, when tremendous drains were placed on the supply of high-grade ores in the Minnesota and Michigan areas. In 1947, however, the problem of drilling taconite was solved with the development of rotary piercing. This, coupled with the technological advances in other phases, made mining taconite both practical and economical. Today, almost every major steel company has an interest in a taconite venture. Furthermore, it has been estimated that, in less than 20 years from now, over one-third of the ore requirements of this nation may be supplied from taconites. At this moment, there are 20 jet-piercing machines on the Iron Range which will account for over 1½ million linear feet of 9-in.-diam blasthole during 1956. This will yield 20,000,000 tons of taconite, which is equivalent to 7,000,000 tons of high-grade concentrate or 5,000,000 tons of pig iron.

As is the case in all industrial rocket-flame processes, the energy for rotary piercing is derived from the combustion of oxygen and a hydrocarbon fuel such as kerosene. A third process fluid—water—is employed to cool the burner and to aid in the removal of spallings from the hole. A typical rotary piercing blowpipe is shown schematically in Fig. 2.

The process fluids are fed through the rotary joint on the upper end of the blowpipe. The oxygen and fuel oil pass through connecting tubes to the combustion chamber. Water, after cooling the burner, is ejected radially at the mouth

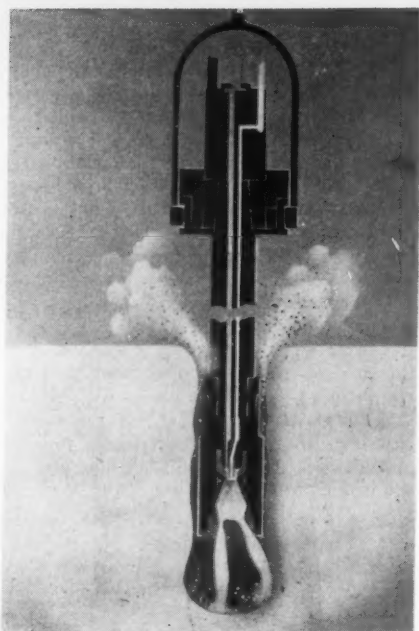


Fig. 2 Schematic of typical rotary piercing blowpipe

of the burner. At this point, the combustion products mix with the water to form steam, which facilitates the removal of spallings from the hole, which will vary from 20 to 50 ft deep. The depth capacity is limited to the length of the blowpipe.

Taconite ore formations are in layered strata. These layers have different spalling characteristics, which lead to the formation of restricting collars. In order to increase penetration rates, development work led to the use of multi-orifice burners within a rotating blowpipe. This combination is particularly effective in collar removal. Fig. 3 illustrates why the rotary blowpipe is effective in removing obstructing collars. In this illustration, piercing is proceeding in a normal manner until a seam is encountered. The stone adjacent to the seam is relieved of stress and does not spall as rapidly as the more massive sections, thus causing a collar to develop. After retracting the blowpipe slightly, one or more of the angular flames are directed at the collar. After a sufficient time, the obstruction is removed.

A factor which must be considered in the design of burners is abrasion by hard rock spallings. This can cause flame distortion from worn orifices or flame dilution from cooling water leaks. An average orifice tip will usually last for 200 hours of operation, during which 4000 ft of hole will be produced.

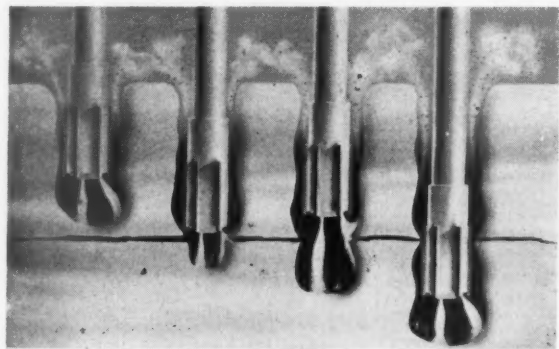


Fig. 3 Removing an obstruction with a rotary blowpipe

Losses to the cooling medium have a secondary part in burner design. The heat loss, which is on the order of 10 per cent of the total heat input, may be reduced through improved design. However, additional manufacturing costs are not justified by the possible increased service life. This is particularly true since the wear which the burner receives from the sandblasting action is usually the controlling factor of the useful service life. Where operations of the magnitude of the present taconite industry are considered, significant savings can be realized from a small reduction in unit cost.

The development of reaction-burner processes must of necessity go beyond the blowpipe itself. In the case of rotary piercing, successful design of the rotary blowpipe necessitated the development of a suitable machine design. Such a machine is shown in Fig. 4, and is called the jet piercing or JPM machine. The JPM machine is built for round-the-clock operation at temperatures down to -35°F . Self-propelled, the 40-ton unit can move from one hole to the next over rugged terrain, be set level, and resume operations in less than 20 min without need for the operator to leave the cab. The machine has a 60-ft mast from which the 55-ft blowpipe is suspended. The blowpipe is rotated by a turntable mounted on the front of the machine. Process fluid supply—a major problem in mining terrain and Minnesota winter temperatures—is generally accomplished by means of crawler-mounted satellite units, which are properly winterized. A JPM during winter operation on the range is shown in Fig. 5. Using this equipment, piercing speeds in the Mesabi Range average from 15 to 23 ft per hour compared to 2 to 5 ft per hour with churn drills.



Fig. 4 JPM machine in operation at a Minnesota taconite mine



Fig. 5 Winter operation on the Mesabi Range

Suspension Piercing

Rotary-piercing machines cannot be used in every jet piercing installation for two reasons: First, maximum hole depth is not sufficient for many crushed stone quarries, since with the rotary burner the hole is limited by the practical length of the mast. Second, the production rate of most crushed stone quarries does not justify the high capital investment for a machine of this type. A simpler and less expensive machine and process were required—hence the development of suspension piercing, which differs from rotary piercing primarily with respect to the burner.

In contrast to the multi-orifice burner on the rotary blowpipe, a single, axial flame provides the energy in the suspension piercing process. As may be anticipated, this type of blowpipe is not as effective as the rotary in penetrating cracks, seams, or melty areas. It must therefore be limited to the more spallable materials, such as granite, sandstone, and quartzite.

The cross section of a typical suspension piercing burner is shown in Fig. 6. The burner configuration in this instance conforms more nearly to classical rocket design. The process fluids are supplied to the blowpipe through hose. Since the blowpipe does not rotate, a rotary joint is not required. Oxygen and fuel pass through tubes to the combustion chamber, which is housed in the lower section of the 20-ft-long blowpipe. As the hole advances, the blowpipe suspended from a steel cable is lowered into the hole. The process fluid hose trail down into the hole after the blowpipe. Holes up to 180 ft deep have been pierced with this process. At

this depth, no difficulty is experienced with the removal of debris and spallings from the hole.

Fig. 7 shows the flame of a suspension piercing burner above the hole. Directly below the flame is the casing pipe. A casing pipe is used to prevent excessive washback into the hole when a hole is started in a hollow or depression. With this type of rocket flame, piercing speeds in the spallable formations have been known to exceed 50 ft per hour. Piercing rates in granite average approximately 20 ft per hour.

The relative simplicity of the suspension piercing machines is shown in Fig. 8. Suspension piercing machines are actually conversions of standard crawler-mounted churn drills. Hydraulic leveling jacks are provided on most rigs. Recently, another machine, shown in Fig. 9, was placed in operation on the St. Lawrence Seaway Project in Canada.

After the completion of blasthole drilling with suspension piercing equipment, the holes are loaded with explosives and detonated. The picture of a typical blast in a granite quarry a few milliseconds after detonation is shown in Fig. 10. A well fragmented rock pile ready for crushing and sizing is a prerequisite in the crushed stone industry.

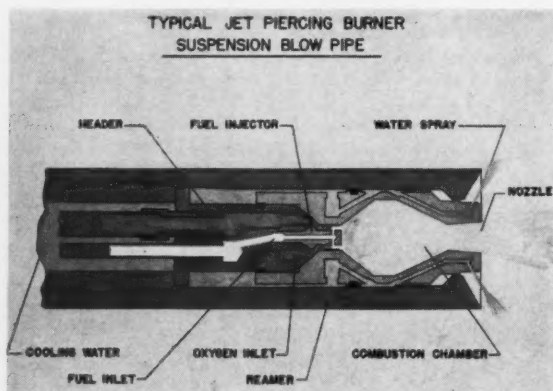


Fig. 6 Schematic of jet piercing burner for suspension blowpipe



Fig. 7 Suspension blowpipe flame



Fig. 8 Suspension piercing machine



Fig. 9 Suspension piercing machine for St. Lawrence Seaway Project



Fig. 10 Blast in crushed stone quarry

Jet Channeling

The versatility of the reaction burner is illustrated in its adaptation for dimension stone channeling. In this industry, the objective is to obtain large undamaged blocks of stone from its native formation. The operation, therefore, is somewhat comparable to a machining operation. In order to "free" the stone, large channels or slots must be cut in the formation outlining the desired block of stone. A typical quarry is illustrated by Fig. 11.

Channels or slots vary in length from 10 ft to well over 100 ft. The depth will range from as little as 1 ft up to 30 ft. Application of the rocket principle for channeling has dictated many innovations in quarrying procedure. Higher production and lower costs have been realized. As a result, 25 per cent of all channeling done in granite quarries in 1956 was done using the rocket flame. This amounts to 150,000 sq ft of channeling, or 2,500,000 cu ft of granite. At the present time, most major granite producers have at least one jet channeling machine in operation.

A typical jet channeling operation is shown in Fig. 12 at



Fig. 11 Typical dimension stone quarry

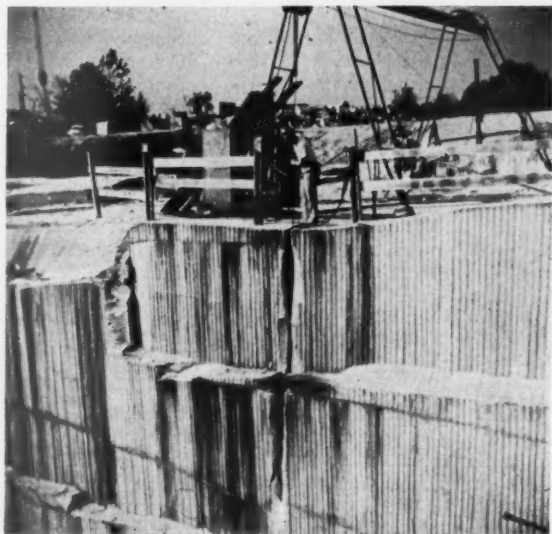


Fig. 12 Start of channel with jet channeling blowpipe

its start. In operation, the jet channeling blowpipe directs a single reaction flame into the stone in the direction of the required channel. Cooling water, instead of being ejected radially as in the hole piercing process, is directed away from the advancing face of the channel. After the channeling operation is under way, the blowpipe is moved vertically over the full depth of the channel, removing a 1- to 2-in-thick layer of stone. This is illustrated in Fig. 13. The pneumatic wash of the flame is used to keep the completed channel clean and unobstructed. Channel cleaning in itself is an interesting problem. In many cases, up to one ton per hour of stone spallings is deposited in the base of the channel. Since these channels are often 15 ft deep, with an effective width of only 4 in., the disposal problem obviously becomes quite important.

An interesting sidelight in the use of reaction processes for jet channeling is the use of natural forces to increase performance. For many years quarry operators have been plagued with rock pressure, caused by internal stresses in the stone dating back to the period of geological formation. This internal pressure will cause the stone to expand into any opening which is made. Tests made by the Bureau of Mines indicate that a granite formation may expand up to $1\frac{1}{2}$ in. for each 100-ft section being relieved. Thus any tool which cuts a channel the exact size of the tool itself is subject to entrapment as the stone expands. With rocket flame equipment, however, a channel considerably wider than the blowpipe is normally made and thus eliminates the possibility of jammed tools. The internal pressure increases the channeling rates by prestressing the stone prior to the thermal shock of the flame. Channeling rates in granite under pressure have been known to exceed 50 sq ft per hour. Normally, however, jet channeling rates in quarries throughout the country average between 15 and 28 sq ft per hour. This is in contrast to mechanical methods which will average from 3 to 7 sq ft per hour.



Fig. 13 Jet channeling blowpipe in operation

Stone Shaping and Finishing

Small manually operated rocket flame blowpipes are now being used to shape and finish many types of industrial stone. For example, a shaping blowpipe may be used to form a compound-angled surface on a large granite drain pad. The torch utilizes the basic design of the piercing and channeling blowpipes. Cooling water from the blowpipe is directed on the stone alongside the flame, giving the operator greater control over the spalling action. If this is not done, the high level of radiant heat transfer of the flame causes uncontrolled spalling on a completed section.

As previously indicated, shaping blowpipes may be used to impart different finishes to stone. Flame-finished stone has a natural warmth and luster not obtainable with mechanical finishing methods. The flame finish is comparable to the natural split of the stone. Since the spalling action breaks

the stone along natural cleavage planes or crystal boundaries, the luster and beauty of the mineral constituents are retained. This is not true of the various mechanical methods where an abrasive or a steel tool is used. In this case, the mineral crystals are damaged, leaving a comparatively dull finish.

One of the most useful advantages that can be realized with rocket flame equipment is the ability to work thinner sections without cracking the stone. This is true for both shaping and surface finishing operations. Thus, in many cases where additional thickness and weight are required to prevent damage during mechanical shaping or finishing, substantial cost savings may now be realized. Using the rocket flame, a larger salable surface can be obtained from the same quantity of stone quarried. Freight costs, which represent a very large portion of the over-all cost of stone products, will be greatly reduced and permit the industry to extend the use of dimension stone for items such as building stone, veneer, and curbing, in competition with concrete and other synthetic stones.

Principles of Industrial Rocket Burner Design

Although general principles and technology are similar, there are basic differences between the design of rocket equipment for military use and for industrial purposes. Military specifications usually require maximum thrust and minimum weight. Industrial rocket equipment is usually designed for low-cost operation over extended periods with minimum maintenance. In industrial design, attention is focused on the effect of the flame on an object rather than the effect of the flame on the burner or rocket motor. During development on industrial applications of the rocket principle, it was necessary to obtain fundamental information beyond the area covered by classical combustion theory and nozzle design. Several of the variables that were found to be of primary interest are described here briefly. They are heat transfer, flame momentum, flame geometry, and noise.

Heat Transfer

Heat transfer rates of three burners at varying fuel ratios are shown in Fig. 14 as a function of standoff, or the distance from the mouth of the nozzle to the workpiece. The three plots show the effect of chamber pressure on heat transfer rates. Designed for the same mass flow, the three burners operate at different chamber pressures, with each individual nozzle calculated for expansion of the gases to atmospheric pressure. For this series of tests, no attempt was made to restrict mixing of the flame with the atmosphere. The mixing effect is clearly evident at standoff distances greater than 4 in. The change in relative position of the higher fuel ratio runs as standoff is increased is particularly interesting. At

HEAT TRANSFER VS STANDOFF

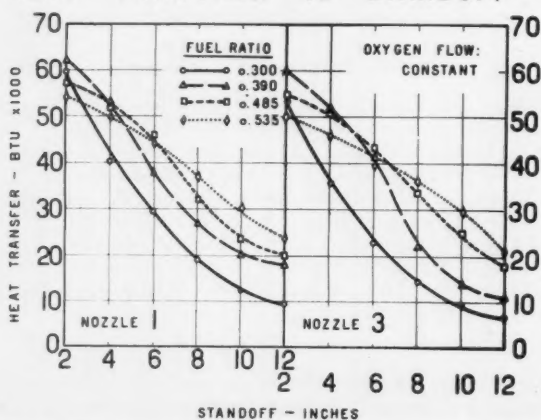


Fig. 14 Heat transfer characteristics as a function of standoff

close standoff distances, heat transfer rates correspond to the temperature conditions in the chamber; however, as mixing becomes an important function, heat transfer rates more nearly reflect the total heating value of the fuel.

Heat transfer rates at standoff distances less than 4 in. decrease as the chamber pressure increases. This is in accordance with the change in mouth temperature for increasing chamber pressure and expansion to atmospheric pressure.

Flame Momentum

Flame momentum is shown in Fig. 15 as a function of standoff distance. As in tests mentioned above, there was no attempt to eliminate mixing with atmospheric air. Over distances up to 12 in., there is an almost negligible change in momentum. This leads to the conclusion that for standoff distances up to 12 in. the decrease in gas velocity is compensated by the increased mass due to air mixing.

FLAME MOMENTUM VS STANDOFF

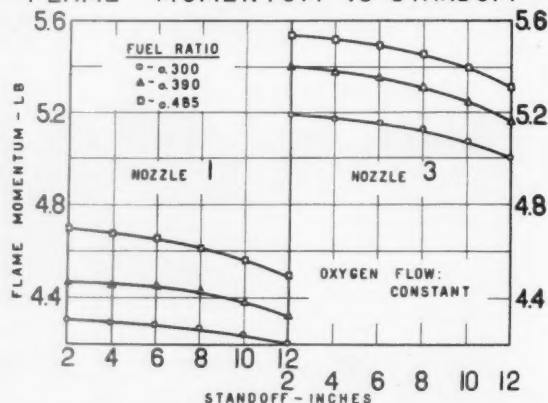


Fig. 15 Momentum characteristics as a function of standoff

There is one misleading aspect to these results which show that the flame momentum increases with fuel ratio, expressed as lb fuel per lb of oxygen. For these tests, the oxygen flow was maintained constant and therefore an increase in fuel ratio corresponds to a slight increase in mass flow. Thus any apparent increase in flame momentum is at least in part due to the increased mass flow. Excess fuel and the possibility of combustion taking place with oxygen in the air appear to have no apparent effect of flame momentum.

Flame Geometry

Flame geometry must be considered when applying a rocket flame to industrial processes. It is a function primarily of nozzle design, chamber pressure and fuel ratio. The chamber pressure for a particular nozzle may be increased by increasing the mass flow. However, varying the chamber pressure in this manner is not satisfactory, since a nozzle design is efficient only over a relatively small variation from the design pressure. If the flow is increased so that the chamber pressure exceeds this range, unpredictable flame geometry will result. When a high chamber pressure is desired, more predictable results can be obtained by using a nozzle designed for that pressure.

A very broad flame front, typical of high fuel ratios, is desirable in instances where area heating plays an important part in the process. Where exacting control is required in very small areas, a sharper or needlelike flame is desirable. This is particularly true for shaping or sculpturing stone. In such cases, optimum conditions of heat transfer and flame momentum for a particular mass flow are often overridden by strict requirements of flame geometry.

Some typical flame configurations due to variations of fuel ratio, total mass flow, and design operating pressure are shown in Fig. 16.

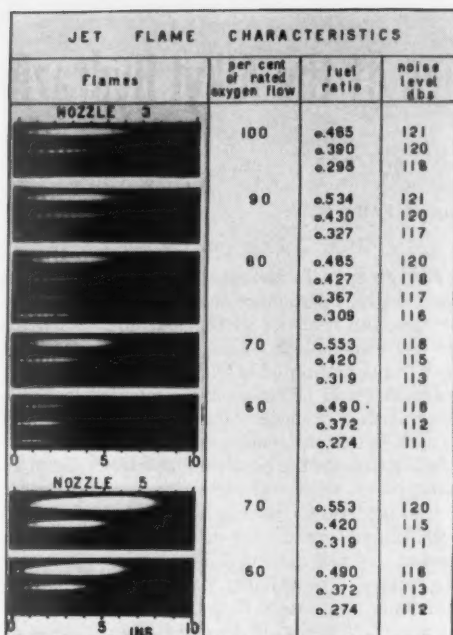


Fig. 16 Flame geometry

Noise

The very items which contribute to the success of a process, namely, flame velocity and temperature, are contributing to another less desirable result—noise. Sometimes the problem is simplified by the process itself. For example, in jet piercing after the first few feet of hole have been pierced, the hole does an extremely effective job in muffling noise. Once this point is reached, a jet piercing machine is probably the quietest of all drillings rigs. Unfortunately, this is not so with jet channeling, where the flame is never confined. The longer the channel gets, the more area is open and exposed for radiation of noise. Several other processes such as stone shaping and surface cleaning lack inherent characteristics which tend to muffle or reduce noise.

A great deal of attention is being focused on this problem in an effort to achieve the minimum noise level compatible with the required performance. At the present time, the effort to control or reduce over-all noise is confined primarily to documenting characteristics of various burner designs and modifications. Noise profiles for every burner are taken and compared with the design criteria used. There is little sound level difference between high pressure and low pressure burners, as may be seen in Fig. 16.

Another aspect of sound is the effect of geometry and length of the supply system on the performance of reaction processes. On virtually every installation, the configuration of the system is different with the exception of the burner proper. Many investigators have shown the effect of the supply system on combustion stability and burner performance. The very nature of some industrial reaction processes dictates that control valves and other regulating equipment must often be as far as 200 ft away from the burner. For economical considerations, it is desirable to use low pressure systems, i.e., less than 50 psi, in industrial applications, even though such systems are inherently unstable. Many times this has caused considerable difficulty. It has been shown that burners, which tend to be unstable, are much more sensitive to the effect of feed line length and configuration. In fact, under some feed line length configurations, continued ignition has been impossible with burners that otherwise operated very satisfactorily.

Conclusion

Industrial applications of the rocket principle are still in their early stages of development. To date, most industrial work has centered around the mining and quarrying industries, where application of the rocket principle has resulted in higher production and lower costs.

Effect of Earth's Oblateness

(Continued from page 406)

For near-polar orbits ($i \doteq \pi/2$) the potential varies with latitude. However, for a fixed distance r_0 the average potential is, from Equation [4]

$$V_{avg} = -\frac{GM}{r_0} \left(1 - \frac{JR^2}{6r_0^2} \right)$$

In other words, for such orbits the effect of the earth's equatorial bulge is to reduce the average potential and force on the satellite. To maintain the fixed distance the mean speed of the satellite is decreased and hence the period is increased.

For long-lived satellites the effects of gravitational anomalies, higher-order terms in the potential function and the attraction of the sun and moon will conspire to modify somewhat the above results.

The author wishes to thank A. D. Wheelon for helpful discussions.

References

- 1 Lindsay, R. B., "Physical Mechanics," D. Van Nostrand Co., New York, 1950.
- 2 Blitzer, L., Weisfeld, M., and Wheelon, A. D., *Journal of Applied Physics*, vol. 27, pp. 1141-1149, 1956. Plus references.
- 3 Jeffreys, H., "The Earth: Its Origin, History and Physical Constitution," 3rd edit., University Press, Cambridge, England, 1952.

Flight Path of an Electrically Propelled Space Ship

(Continued from page 414)

- a. Stuhlinger, E., "Electrical Propulsion System for Space Ships with Nuclear Power Source," *J. Astronautics*, vol. 2, 1955, p. 149; vol. 3, 1956, pp. 11, 39.

(Both papers present design and performance data of an electrically propelled space ship.)

- 2 a. Shepherd, L. R., and Cleaver, A. V., "The Atomic Rocket. I, II, III, IV," *J. Brit. Interplanetary Soc.* vol. 7, 1948, pp. 185, 234; vol. 8, 1949, pp. 23, 59.

- b. Forbes, G. F., "The Trajectory of a Powered Rocket in Space," *J. Brit. Interplanetary Soc.*, vol. 9, 1950, p. 75; "The Thrust Available from Electronic Accelerators," *J. Space Flight*, vol. 4, 1952.

- c. Spitzer, L., Jr., "Interplanetary Travel Between Satellite Orbits," *J. Brit. Interplanetary Soc.*, vol. 10, 1951, p. 249; *J. Amer. Rocket Soc.*, vol. 22, 1952, p. 92.

- d. Preston-Thomas, H., "Interorbital Transport Techniques," *J. Brit. Interplanetary Soc.*, vol. 11, 1952, p. 173.

- e. Tsien, H. S., "Take-off From Satellite Orbit," *J. Amer. Rocket Soc.*, vol. 23, 1953, p. 233.

- f. Lawden, D. F., "Fundamentals of Space Navigation," *J. Brit. Interplanetary Soc.*, vol. 13, 1954, p. 87.

- g. Michielsen, H., "The Case for the Low Acceleration Space Ship," *Astro. Acta*, (to appear).

- 3 von Braun, W., "The Mars Project," University of Illinois Press, Springfield, 1953. (Applies a similar method to calculate the trajectory of a chemically propelled space ship.)

- 4 von Braun, W., "The Exploration of Mars," Viking Press, 1956. (Presents one possible design of a landing craft capable of descending to Mars and ascending again to the orbiting space ship.)

The Physical and Chemical Properties of the Alkyl Hydrazines

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Some of the major physical and chemical properties of a large number of alkyl-substituted hydrazines are presented to illustrate the general effects of substitution on the properties of hydrazine. Those hydrazine derivatives currently of greatest interest in the propellant field, the methyl hydrazines, are discussed in greater detail. In general, increasing the organic content is found to make the compound more organic in character and less like hydrazine. The variations in properties observed can be explained in terms of the normal effects of organic substitution and the effects of hydrogen bonding in hydrazine. Some of the methods of production of alkyl hydrazines are discussed briefly.

HYDRAZINE has, in the past several years, proved to be of considerable interest as a propellant. Experience has shown it to have many outstanding advantages and some limitations. These limitations have naturally led to the consideration of hydrazine derivatives, in the hope of retaining the advantages of hydrazine without its limitations. One of these derivatives, unsymmetrical dimethyl hydrazine, has already been studied somewhat extensively.

The very marked differences in properties of hydrazine and unsymmetrical dimethyl hydrazine are likely to cause us to lose sight of the similarities of the two. The alkyl hydrazines represent a clearly defined family of compounds and the variations in their properties are related to their structures. Since in a study of these compounds much value can be obtained from a consideration of such relationships, I have attempted to compile in this paper data on the physical and chemical properties of a variety of alkyl hydrazines to show the general effects of substitution on properties. Some physical properties of a number of types of alkyl hydrazines are presented in Table 1.

The first group of compounds illustrates the effect of the length of the alkyl chain. These materials are found to follow the normal behavior for homologous series of organic compounds; i.e., increasing the chain length in general increases both the freezing and boiling points. It would be well to comment at this point on the apparently anomalous behavior of hydrazine itself. Hydrazine has a higher freezing point and boiling point than several of the substituted hydrazines. This behavior is due to hydrogen bonding; i.e., association of the molecules through bonding of hydrogen atoms on adjacent molecules. This is discussed more thoroughly by Class, Aston, and Oakwood (1).² As is to be expected, it is found that increasing chain length decreases solubility in water and increases solubility in organic solvents.

The second group of compounds presented in Table 1 illustrates the effect of isomeric forms of alkyl groups. Isomerism of the alkyl groups is found to have a small but definite effect on the boiling point; the *n*-alkyl group gives a higher boiling point. This isomerism does not have a significant effect on solubility characteristics. This group of compounds also illustrates the increase in boiling point with increased chain length of alkyl group.

The third group of Table 1 illustrates the effect of isomerism with respect to the placement of alkyl group on the nitrogen. In this case, the behavior of the two dimethyl hydrazines appears to be anomalous. As was the case with hydrazine itself, this can be attributed to hydrogen bonding.

The fourth group of compounds presented in Table 1 illustrates the effect of successive substitution of single groups. In this case, hydrogen bonding appears to be the controlling factor in determining the physical properties. From analogy to hydrocarbons, we would expect increasing degree of substitution to increase the boiling point and the freezing point. However, since increasing substitution decreases the hydrogen bonding, we find an actual decrease in boiling point and freezing point. The solubility properties change in the expected manner: All except trimethyl hydrazine are very soluble in water; trimethyl hydrazine is slightly soluble. Hydrazine is insoluble in most organic solvents and monomethyl hydrazine is very soluble in most organic solvents, whereas dimethyl and trimethyl hydrazine are miscible in all proportions with most organic solvents at room temperature.

In general, we see that the effects of substitution of alkyl groups for the hydrogens of hydrazine follow the behavior expected of families of organic compounds except for the very pronounced effect of hydrogen bonding. We can state this another way: Increasing the alkyl content of substituted hydrazines makes them more like organic compounds and less like hydrazine.

At least at the present time, the compounds of greatest interest as propellants are the methyl hydrazines, since they retain many of the desired characteristics of hydrazine. Table 2 presents a more detailed comparison of hydrazine and four methyl hydrazines.

Again we can see by comparison of such properties as boiling point, vapor pressure, freezing point, heat of fusion, and heat of vaporization the effect of hydrogen bonding.

The chemical properties of the methyl hydrazines also have been found to vary in a regular manner with degree of substitution. Except for the limitations of the number of hydrogens available for the normal reactions, monomethyl hydrazine and dimethyl hydrazine undergo most of the reactions of hydrazine. Trimethyl and tetramethyl hydrazine react like hydrazine only in a few instances. The principal chemical properties of interest in propellant use are oxidation, stability and compatibility with materials of construction. With respect to these properties, only hydrazine, monomethyl hydrazine, and unsymmetrical dimethyl hydrazine have been studied extensively. With respect to slow oxidation, e.g., at room temperature, dimethyl hydrazine has been found to be the most sensitive, hydrazine the least sensitive, and monomethyl hydrazine intermediate. With respect to combustion, there are only small differences between the three. In the absence of air, dimethyl hydrazine is the most stable, hydrazine the least stable, and monomethyl hydrazine intermediate, as shown by tests at temperatures up to 600 F. This behavior is also observed for violent decomposition. Hydrazine vapor, in the absence of air, will decompose explosively. Unsymmetrical dimethyl hydrazine has an upper explosive limit of 45 per cent by volume in air.

In considering the compatibility with materials of con-

¹ Presented at the ARS Fall Meeting, Buffalo, N. Y., Sept. 24-26, 1956.

² Assistant Manager, Engineering Research.

³ Numbers in parentheses indicate References at end of paper.

Table 1 Physical properties of typical alkyl hydrazines

Name	Structural formula	Molecular weight	Freezing point, °C	Boiling point, °C at p mm Hg	Density, g/ml at t °C
Hydrazine	H ₂ NNH ₂	32.05	2.0 (2)	113.5 at 760 (2)	1.0085 at 20 (2)
Monomethyl hydrazine	(CH ₃)HNNH ₂	46.07	-52.4 (3)	87.5 at 760	0.871 at 26
Monoethyl hydrazine	(C ₂ H ₅)HNNH ₂	60.10	.....	101.5 at 760 (4)	.....
n-Propyl hydrazine	(C ₃ H ₇)HNNH ₂	74.13	.....	119 at 760 (5)	.....
n-Hexyl hydrazine	(C ₆ H ₁₃)HNNH ₂	116.20	.....	69 at 9	.....
n-Lauryl hydrazine	(C ₁₂ H ₂₅)HNNH ₂	200.36	28-30	.....	.....
Unsymmetrical di-n-butyl hydrazine	(C ₄ H ₉) ₂ NNH ₂	144.26	.....	83 at 16	.....
Unsymmetrical di-iso-butyl hydrazine	[(CH ₃) ₂ CH] ₂ NNH ₂	144.26	.....	63 at 16	.....
Unsymmetrical di-n-propyl hydrazine	(C ₃ H ₇) ₂ NNH ₂	116.20	.....	44 at 16 (6)	.....
Unsymmetrical di-iso-propyl hydrazine	[(CH ₃) ₂ CH] ₂ NNH ₂	116.20	.....	41 at 16 (6)	.....
Symmetrical dimethyl hydrazine	(CH ₃) ₂ NNH(CH ₃)	60.10	-8.92 (7)	81.5 at 760 (8)	0.8274 at 20 (8)
Unsymmetrical dimethyl hydrazine	(CH ₃) ₂ NNH ₂	60.10	-57.21 (9)	63.1 at 760	0.783 at 25
Symmetrical diethyl hydrazine	(C ₂ H ₅) ₂ NNH(CH ₂ H ₅)	88.15	.....	85 at 760 (10)	.....
Unsymmetrical diethyl hydrazine	(C ₂ H ₅) ₂ NNH ₂	88.15	.....	98 at 760	0.790 at 20
Symmetrical di-isopropyl hydrazine	(CH ₃) ₂ CHHNNHCH(CH ₃) ₂	116.20	.....	125 at 760	0.785 at 25 (11)
Unsymmetrical di-iso-propyl hydrazine	[(CH ₃) ₂ CH] ₂ NNH ₂	116.20	.....	130 at 760	.....
Hydrazine	H ₂ NNH ₂	32.05	2.0 (2)	113.5 at 760 (2)	1.0085 at 20 (2)
Monomethyl hydrazine	(CH ₃)HNNH ₂	46.07	-52.4 (3)	87.5 at 760	0.871 at 26
Symmetrical dimethyl hydrazine	(CH ₃) ₂ NNH(CH ₃)	60.10	-8.92 (7)	81.5 at 760 (8)	0.827 at 20 (8)
Unsymmetrical dimethyl hydrazine	(CH ₃) ₂ NNH ₂	60.10	-57.2 (9)	63.1 at 760	0.783 at 25
Trimethyl hydrazine	(CH ₃) ₃ NNH(CH ₃)	74.14	-71.9 (12)	60 at 760 (13)	0.814 at 18 (13)

Table 2 Physical properties of methyl hydrazines

Name	Hydrazine	Monomethyl hydrazine	Symmetrical dimethyl hydrazine	Unsymmetrical dimethyl hydrazine	Trimethyl hydrazine
Structural formula	H ₂ NNH ₂	(CH ₃)HNNH ₂	(CH ₃) ₂ NNH(CH ₃)	(CH ₃) ₂ NNH ₂	(CH ₃) ₃ NNH(CH ₃)
Molecular weight	32.05	46.07	60.10	60.10	74.13
Boiling point, °C at 760 mm Hg	113.5 (2)	87.5	81.5 (9)	63.1	60 (13)
Vapor pressure, mm Hg at 25 °C	14.38 (2)	49.63 (3)	70.1 (7)	156.8 (9)	148.7 (12)
Heat of vaporization at 25 °C, cal/mole	10,700 (2)	9648 (3)	9400 (7)	8366 (9)	7949 (12)
Freezing point, °C	+2 (2)	-52.4 (3)	-8.92 (7)	-57.2 (9)	-71.9 (12)
Heat of fusion, cal/mol	3025 (2)	2491 (3)	3296 (7)	2407 (9)	2267 (12)
Cp (liq.) at 25 °C, cal/deg/mole	23.62 (2)	32.25 (3)	40.88 (7)	39.21 (9)	44.45 (12)
Density, g/ml at t °C	1.0085 at 20 (2)	0.871 at 26	0.827 at 20 (8)	0.783 at 25	0.814 at 18 (13)
Viscosity, centipoises at 25 °C	0.90 (2)	.....	.....	0.48	.....
Viscosity, centipoises at -55 °C	.....	19.0	.....	4.60	.....
Explosive limits in air, % by vol	4.6-100 (14)	.....	.....	3-45	.....
Entropy of the ideal gas at 25 °C and 1 atm, cal/deg/mole	57.41 (2)	66.61 (3)	74.39 (7)	72.82 (9)	79.45 (12)
Heat of formation, kcal/g mole	+12.0	+12.7	+12.2	+11.3	.....
Heat of combustion, kcal/g mole	-148.6 (15)	-311.7 (15)	-473.5 (15)	-472.6 (15)	.....

struction, both the effect of the liquid on the material of construction and the effect of the material of construction on the liquid must be considered.

With respect to metallic materials of construction, the three hydrazines are similar in behavior. Unsymmetrical dimethyl hydrazine is somewhat less corrosive to ferrous alloys and more stable than hydrazine. Neither hydrazine nor dimethyl hydrazine produces any significant attack on aluminum. Any metal useful for hydrazine may be used for dimethyl hydrazine and, in addition, lower alloy steels and even mild steel are useful in some cases. Monomethyl hydrazine is very similar to hydrazine in its requirements for metallic materials of construction.

With respect to nonmetallic materials of construction, monomethyl and dimethyl hydrazine produce more severe attack than does hydrazine on many organic materials, such as elastomers. This is to be expected from their closer similarity to organic compounds in solubility properties. Teflon, Kel-F, and polyethylene are satisfactory for both methyl hydrazines.

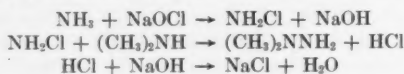
There are two general methods available for the synthesis of alkyl hydrazines and a number of special methods suitable only for the synthesis of certain ones.

One general method is the alkylation of hydrazine. This can be represented by



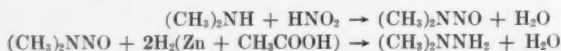
This reaction has been successfully used to synthesize a wide variety of alkyl hydrazines. It works best for producing monosubstituted hydrazines containing relatively high molecular weight groups. Although it can be used to synthesize products such as monomethyl and dimethyl hydrazine, its applicability is limited by the tendency to excessive alkylation, producing azinium salts.

Another general method of synthesis of alkyl hydrazines is via chloramine. This is analogous to the Raschig method for the preparation of hydrazine. It can be represented by



This reaction has been used successfully to prepare a wide variety of monoalkyl and dialkyl hydrazines. It has not been applied successfully to the production of tetralkyl hydrazines and it is less effective for high molecular weight alkyl hydrazines.

A special method, suitable for the production of unsymmetrical dialkyl hydrazine is the reduction of nitrosodialkylamine. This can be represented by



This reaction is not applicable to any hydrazines except unsymmetrical disubstituted ones.

A number of other reactions have been reported for the preparation of specific hydrazine derivatives (2). Examples include the alkylation of benzaldehyde hydrazone, the hypochlorite oxidation of N-alkyl ureas, and the hydrogenation of hydrazones or azines.

Summary

A study of the general physical and chemical properties of the alkyl hydrazines shows their behavior to be that which would be expected from analogy to related organic compounds, except for the very pronounced effect of hydrogen bonding. Increasing the organic content is found to make the compound more organic in character and less like hydrazine.

Of the alkyl hydrazines, the current greatest interest for propellant application is in the methyl hydrazines. A more detailed comparison of the physical properties of the methyl hydrazines shows these to be greatly influenced by hydrogen bonding. In comparison with hydrazine, unsymmetrical dimethyl hydrazine is more susceptible to slow oxidation, more stable in the absence of air, less corrosive to ferrous alloy materials of construction, and more corrosive to organic materials of construction. In all of these respects, monomethyl hydrazine is intermediate between the two.

With respect to methods of preparation and hence availability, hydrazine, monomethyl hydrazine, unsymmetrical dimethyl hydrazine and many others can be prepared by modifications of the synthesis from chloramine. Other methods of preparations are available for certain compounds but these lack general applicability.

References

- 1 Class, J. B., Aston, J. G., and Oakwood, T. S., "Trimethylhydrazine and Tetramethylhydrazine," *Journal of the American Chemical Society*, vol. 75, 1953, pp. 2937-2939.
- 2 Clark, C. C., "Hydrazine," Mathieson Chemical Corp., Baltimore, first edit., 1953, pp. 19-29, 30-36.
- 3 Aston, J. G., Fink, H. L., Janz, G. J., and Russell, K. E., "The Heat Capacity, Heat of Fusion and Vaporization, Vapor Pressures, Entropy and Thermodynamic Functions of Methylhydrazine," *Journal of the American Chemical Society*, vol. 73, 1951, pp. 1939-1943.
- 4 "Handbook of Chemistry and Physics," Chemical Rubber Publishing Co., Cleveland, 37th edit., 1955.

5 Stolle, Robert, and Benrath, Alfred, "The Action of Iodine and of Halogenated Substances on the Metallic Derivatives of Dibenzoylhydrazine," *J. Prakt. Chem.*, vol. 70, 1904, pp. 263-280.

6 Zimmer, H., Audrieth, L. F., Zimmer, M., and Rowe, R. A., "The Synthesis of Unsymmetrically Disubstituted Hydrazines," *Journal of the American Chemical Society*, vol. 77, 1955, pp. 790-793.

7 Aston, J. G., Janz, G. J., and Russell, K. E., "The Heat Capacity, Heats of Fusion and Vaporization, Vapor Pressures and Entropy of Symmetrical Dimethylhydrazine," *Journal of the American Chemical Society*, vol. 73, 1951, pp. 1943-1945.

8 Knorr, L., and Kohler, A., "Über das Symmetrische Dimethylhydrazin," *Ber.*, vol. 39, 1906, pp. 3257-3265.

9 Aston, J. G., Wood, J. L., and Zolki, T. P., "The Thermodynamic Properties and Configuration of Unsymmetrical Dimethylhydrazine," *Journal of the American Chemical Society*, vol. 75, 1953, pp. 6206-6204.

10 Harries, C. D., "Aethanhydrazoathane," *Ber.*, vol. 27, 1894, pp. 2276-2282.

11 Barriek, L. D., Drake, G. W., and Lochte, H. L., "The Parachor and Molecular Refraction of Hydrazine and Some Aliphatic Derivatives," *Journal of the American Chemical Society*, vol. 58, 1936, pp. 160-162.

12 Aston, J. G., Zolki, T. P., and Wood, J. L., "The Thermodynamic Properties and Configuration of Trimethylhydrazine—Identification and Correction for a Major Impurity," *Journal of the American Chemical Society*, vol. 77, 1955, pp. 281-284.

13 Class, J. B., and Aston, J. G., "Synthesis and Properties of Trimethylhydrazine," *Journal of the American Chemical Society*, vol. 73, 1951, p. 2359.

14 Audrieth, L. F., and Ogg, B. A., "The Chemistry of Hydrazine," John Wiley and Sons, New York, 1951, p. 97.

15 Aston, J. G., Rock, E. J., and Isserow, S., "The Heats of Combustion of the Methyl Substituted Hydrazines and Some Observations on the Burning of Volatile Liquids," *Journal of the American Chemical Society*, vol. 74, 1952, pp. 2484-2486.

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The Effect of Chemical Structure on the Hypergolic Ignition of Amine Fuels

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A systematic study of the relationship between chemical structure and hypergolic ignition of amine fuels with white fuming nitric acid oxidizer is presented. A simple drop test ignition delay apparatus was used to obtain the experimental data. Comparisons are made between the hypergolic characteristics of primary, secondary, and tertiary amines as well as the effect of substituent groups, such as methyl, hydroxy, and phenyl, on the α - and β -carbon atoms of various amines.

Introduction

REACTION Motors, Inc., has been vitally interested in the ignition phenomena of liquid rocket engines and has undertaken extensive research, under the sponsorship of the U. S. Navy Bureau of Aeronautics, in this field. Although the work involved both the physical and chemical aspects of this phenomena, this paper will be limited to a small portion of the work carried on in the chemical aspects of hypergolic ignition.

The principal objective of this program was to study the relationship between chemical structure and hypergolicity and, if possible, to deduce from this a general correlation between the chemical structure of a fuel and its ignition characteristics with white fuming nitric acid. Although a large variety of chemical compounds were studied, this paper shall be limited to studies of the aliphatic amines. In these studies white fuming nitric acid of the following composition was employed:

HNO ₃	98.3 to 98.6%
NO ₂	0.4 to 0.2%
H ₂ O	1.3 to 1.1%

The Apparatus

The apparatus employed in these studies was a simple drop test ignition delay apparatus which is shown schematically in Fig. 1. The light from the projector lamp is focused through a lens and diaphragm system to the glass reaction vessel. The light then passes through the transparent white fuming nitric acid, very close to its surface, and strikes the phototube to the right of the vessel. The phototube energizes a Fisher-Serfass electronic relay. When the fuel strikes the surface of the WFNA it causes an indentation in the surface of the acid. The light beam is thus reflected and refracted so that it no longer impinges on the phototube, hence activating the electronic relay A which starts the timer mechanism. The two aluminum probes located immediately over the reaction vessel detect ionization due to the flame when the reacting propellants ignite. The signal generated activates the second relay B which stops the timer. The latching relays were installed to prevent restarting the timer if secondary ignition occurred.

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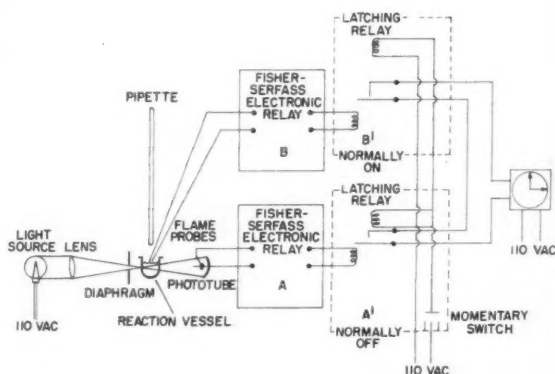


Fig. 1 Schematic diagram of ignition delay apparatus

Admittedly, this is a rather crude apparatus, and the values obtained are not claimed to be the same values which would be obtained in a rocket engine. But results obtained with this apparatus were compared with those of six other types employed in the United States, and it was found that in evaluating the more active hypergols, that is, of the order of 20 milliseconds or less, the values obtained were comparable with those obtained with the much more elaborate equipment.

Results



1. Primary Aliphatic Amines

A. Linear Amines

Table 1 shows some results obtained with the primary aliphatic amines. It can be seen that, for the saturated structures starting with ethylamine, hypergolicity increases; that is, the ignition delay decreases as the length of the alkyl chain increases up to the six-carbon member. Hypergolicity vanishes at and beyond hexylamine. The ignition delay is a minimum with amylamine. These results indicate that the hydrocarbon portion of the molecule greatly influences reactivity.

Table 1. Primary aliphatic amines—unbranched

Name	Structure	Average ignition delay, sec (ca 23 C)
methylamine	C-NH ₂	not hypergolic
ethylamine	C-C-NH ₂	2.03
propylamine	C-C-C-NH ₂	1.73
butylamine	C-C-C-C-NH ₂	0.95
amylamine	C-C-C-C-C-NH ₂	0.81
hexylamine	C-C-C-C-C-C-NH ₂	not hypergolic
heptylamine	C-C-C-C-C-C-C-NH ₂	not hypergolic
octylamine	C-C-C-C-C-C-C-C-NH ₂	not hypergolic

Name	Structure	Average ignition delay, sec (ca 23 C)
isopropylamine	$\begin{array}{c} \text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C} \end{array}$	0.94
sec-butylamine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C} \end{array}$	0.63
1-methyl-butyl- amine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C} \end{array}$	0.57
1-ethyl-butyl- amine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C} \\ | \\ \text{C} \end{array}$	0.54
1-methyl-amyl- amine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C} \end{array}$	0.49
1-methyl-hexyl- amine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C} \end{array}$	not hypergolic
1-methyl- heptylamine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C} \end{array}$	not hypergolic
tert-butylamine	$\begin{array}{c} \text{C} \\ | \\ \text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C} \end{array}$	not hypergolic
benzylamine	 -C-NH ₂	not hypergolic
p-methoxy- benzylamine	CH ₃ -O-  -C-NH ₂	occasionally hypergolic
1-phenyl-ethyl- amine	$\begin{array}{c} \text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C}_6\text{H}_5 \end{array}$	not hypergolic
2-amino-1- butanol	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C} \\ | \\ \text{OH} \end{array}$	not hypergolic

APRIL

Table 3 Primary aliphatic amines—substituent on β -carbon

Name	Structure	Average ignition delay, sec (ca 23 C)
isobutylamine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C} \end{array}$	not hypergolic
2-ethylhexylamine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C} \\ | \\ \text{C} \end{array}$	not hypergolic
ethanolamine	$\begin{array}{c} \text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{OH} \end{array}$	0.43
ethylenediamine	$\begin{array}{c} \text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{NH}_2 \end{array}$	0.09
β -phenylethylamine	$\begin{array}{c} \text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C}_6\text{H}_5 \end{array}$	0.51
β -3,4-dimethoxyphenylethylamine	$\begin{array}{c} \text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C}_6\text{H}_3(\text{OCH}_3)_2 \end{array}$	0.06
isopropanolamine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{OH} \end{array}$	not hypergolic

The inactivity of N,N-diethyl-decylamine and N,N-dimethyl-dodecylamine indicates that for the asymmetric tertiary amines, hypergolicity is governed by the least reactive alkyl group present.

B. Hydroxy Substituted Compounds

The results obtained for tertiary aliphatic amines containing hydroxy substituents on the alkyl portion of the molecule are shown in Table 7. The enhancing effect of the hydroxy group at the β - and α -carbons is apparent. The inert nature of triethanol amine and 3-dimethylamino-1,2-propanediol may be due to the excessively high viscosities of these compounds.

4 Relative Order of Hypergolicity of Isomers Containing Six Carbon Atoms

A comparison of the relative activities of primary, secondary, and tertiary amine isomers containing six carbon atoms is given in Table 8. It can be seen that the hypergolicity increases in going from a primary to a secondary to a tertiary amine structure. Except for the primary amines, hypergolicity increases as the symmetry of the molecule increases.

Conclusions

1 In order for a saturated aliphatic primary amine to be hypergolic, it must have at least one, but no more than two, carbon-hydrogen bonds at the α -carbon position.

2 Substitution of a methyl group for a secondary hydrogen atom at the α -carbon position is conducive to hypergolicity.

3 Substitution of a methyl group for a secondary hydrogen atom at positions further removed from the nitrogen than the α -carbon is detrimental to hypergolicity.

Table 4 Secondary aliphatic amines—unbranched symmetrical

Name	Structure	Average ignition delay, sec (ca 23 C)
diethylamine	$(\text{C}_2\text{H}_5)_2\text{NH}$	0.45
dipropylamine	$(\text{C}_3\text{H}_7)_2\text{NH}$	0.17
dibutylamine	$(\text{C}_4\text{H}_9)_2\text{NH}$	0.15
diamylamine	$(\text{C}_5\text{H}_{11})_2\text{NH}$	0.26
dihexylamine	$(\text{C}_6\text{H}_{13})_2\text{NH}$	not hypergolic
diheptylamine	$(\text{C}_7\text{H}_{15})_2\text{NH}$	not hypergolic
dioctylethylamine	$(\text{C}_8\text{H}_{17})_2\text{NH}$	not hypergolic

Table 5 Secondary aliphatic amines—alkyl branched

Name	Structure	Average ignition delay, sec (ca 23 C)
N-methyl-iso-propylamine	$\begin{array}{c} \text{C}-\text{N}-\text{C}-\text{C} \\ | \\ \text{C} \end{array}$	0.47
N-methyl-sec-butylamine	$\begin{array}{c} \text{C}-\text{N}-\text{C}-\text{C}-\text{C} \\ | \\ \text{C} \end{array}$	0.18
N-methyl-iso-butylamine	$\begin{array}{c} \text{C}-\text{N}-\text{C}-\text{C}-\text{C} \\ | \\ \text{C} \end{array}$	not hypergolic
diisopropylamine	$\begin{array}{c} \text{C}-\text{C}-\text{N}-\text{C}-\text{C} \\ | \quad | \\ \text{C} \quad \text{C} \end{array}$	0.15
N-methyl-iso-amylamine	$\begin{array}{c} \text{C}-\text{N}-\text{C}-\text{C}-\text{C}-\text{C} \\ | \\ \text{C} \end{array}$	not hypergolic
di-sec-butylamine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{N}-\text{C}-\text{C}-\text{C} \\ | \quad | \\ \text{C} \quad \text{C} \end{array}$	0.30
diisobutylamine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{N}-\text{C}-\text{C}-\text{C} \\ | \quad | \\ \text{C} \quad \text{C} \end{array}$	not hypergolic
diisoamylamine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{C}-\text{N}-\text{C}-\text{C}-\text{C}-\text{C} \\ | \quad | \\ \text{C} \quad \text{C} \end{array}$	not hypergolic
bis-(1,3-dimethyl-butyl)amine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{C}-\text{N}-\text{C}-\text{C}-\text{C}-\text{C} \\ | \quad | \quad | \quad | \\ \text{C} \quad \text{C} \quad \text{C} \quad \text{C} \end{array}$	not hypergolic
bis-(2-ethyl-hexyl)amine	$\begin{array}{c} (\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C})_2\text{NH} \\ | \\ \text{C} \end{array}$	not hypergolic

Table 6 Tertiary aliphatic amines—unsubstituted (except for methyl)

Name	Structure	Average ignition delay, sec (ca 23 C)
triethylamine	$(\text{C}_2\text{H}_5)_3\text{N}$	0.07
tripropylamine	$(\text{C}_3\text{H}_7)_3\text{N}$	0.05
tributylamine	$(\text{C}_4\text{H}_9)_3\text{N}$	0.24
triethylamine	$(\text{C}_5\text{H}_{11})_3\text{N}$	not hypergolic
triisobutylamine	$[(\text{CH}_3)_2\text{CHCH}_2\text{CH}_2]_3\text{N}$	not hypergolic
triheptylamine	$(\text{C}_7\text{H}_{15})_3\text{N}$	not hypergolic
N,N-diethyl-decylamine	$\text{CH}_3(\text{CH}_2)_9\text{N}(\text{C}_2\text{H}_5)_2$	not hypergolic
N,N-dimethyl-dodecylamine	$\text{CH}_3(\text{CH}_2)_{11}\text{N}(\text{CH}_3)_2$	not hypergolic

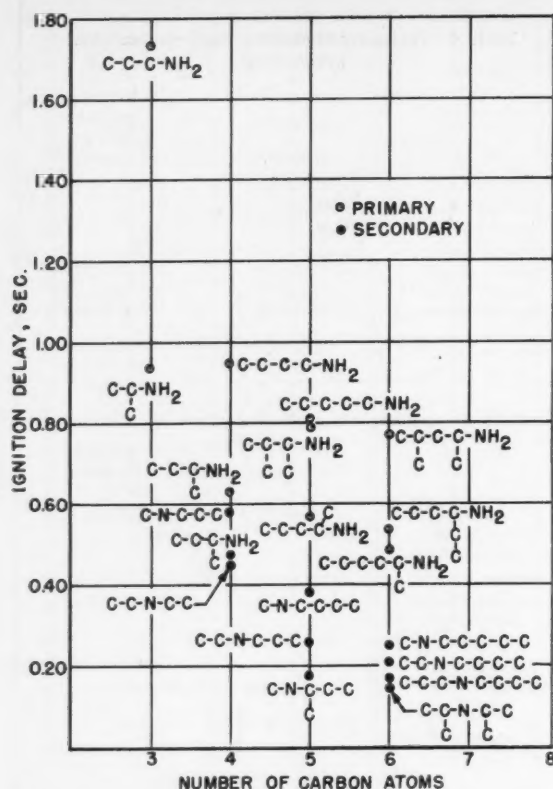


Fig. 3 Comparison of hypergolicity of primary aliphatic amines with secondary aliphatic amines

4 Substitution of hydroxyl, phenyl, or amine groups on the β -carbon enhances hypergolicity.

5 Hypergolicity for primary saturated aliphatic amines is a maximum when the length of alkyl chain is amyl and vanishes when the chain is greater than amyl. For secondary amines, it is a maximum when the length of each alkyl chain is butyl and vanishes when the chain is hexyl or longer. Hypergolicity is a maximum for tertiary saturated aliphatic amines when each alkyl group is propyl, and vanishes when the alkyl group is amyl.

6 Comparing activity on the basis of an equal number of carbon atoms, the order of hypergolicity for the three classes of amines generally is: tertiary > secondary > primary.

Table 7 Tertiary aliphatic amines—containing hydroxy substituents

Name	Structure	Average ignition delay, sec (ca 23 C)
2-dimethylamino-ethanol	$\begin{array}{c} \text{C}-\text{N}-\text{C}-\text{C} \\ | \quad | \\ \text{C} \quad \text{OH} \end{array}$	0.02
2-diethylamino-ethanol	$\begin{array}{c} \text{C}-\text{C}-\text{N}-\text{C}-\text{C} \\ | \quad | \\ \text{C} \quad \text{OH} \end{array}$	0.02
triethanol amine	$\begin{array}{c} \text{C}-\text{C}-\text{N}-\text{C}-\text{C} \\ | \quad | \quad | \\ \text{OH} \quad \text{C} \quad \text{OH} \\ | \\ \text{C}-\text{OH} \end{array}$	not hypergolic
3-dimethylamino-1,2-propanediol	$\begin{array}{c} \text{C}-\text{N}-\text{C}-\text{C}-\text{C} \\ | \quad | \quad | \\ \text{C} \quad \text{HO} \quad \text{OH} \end{array}$	not hypergolic
3-diethylamino-2-propanol	$\begin{array}{c} \text{C}-\text{C}-\text{N}-\text{C}-\text{C}-\text{C} \\ | \quad | \\ \text{C} \quad \text{OH} \end{array}$	0.11
3-diethylamino-propanol	$\begin{array}{c} \text{C}-\text{C}-\text{N}-\text{C}-\text{C}-\text{C} \\ | \quad | \\ \text{C} \quad \text{OH} \end{array}$	0.10
5-diethylamino-2-pentanol	$\begin{array}{c} \text{C}-\text{C}-\text{N}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C} \\ | \quad | \\ \text{C} \quad \text{OH} \end{array}$	0.18
2-dibutylamino-ethanol	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{C}-\text{N}-\text{C}-\text{C} \\ | \quad | \quad | \\ \text{C} \quad \text{OH} \quad \text{C} \\ | \\ \text{C} \\ | \\ \text{C} \\ | \\ \text{C} \end{array}$	0.09

This order is similar to the order of symmetry for these compounds.

7 When viscosity tends to become abnormally high, particularly for the hydroxy amines, erstwhile favorable structural features fail to overcome the inactivation caused by viscosity.

Table 8 Relative activities of primary, secondary and tertiary aliphatic amines containing six carbon atoms

Compound	Structure	Average ignition delay, sec	Compound	Structure	Average ignition delay, sec
<i>Primary</i>			<i>Secondary</i>		
hexylamine	$\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{NH}_2$	not hypergolic			
1-methyl-amylamine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C} \end{array}$	0.49	N-ethyl-butylamine	$\begin{array}{c} \text{H} \\ | \\ \text{C}-\text{C}-\text{N}-\text{C}-\text{C}-\text{C}-\text{C} \end{array}$	0.21
1-ethyl-butylamine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{C}-\text{NH}_2 \\ | \\ \text{C} \\ | \\ \text{C} \end{array}$	0.54	dipropylamine	$\begin{array}{c} \text{H} \\ | \\ \text{C}-\text{C}-\text{C}-\text{N}-\text{C}-\text{C}-\text{C} \end{array}$	0.17
1,3-dimethyl-butylamine	$\begin{array}{c} \text{C}-\text{C}-\text{C}-\text{C}-\text{NH}_2 \\ | \quad | \\ \text{C} \quad \text{C} \end{array}$	0.77	diisopropylamine	$\begin{array}{c} \text{H} \\ | \\ \text{C}-\text{C}-\text{N}-\text{C}-\text{C} \\ | \quad | \\ \text{C} \quad \text{C} \end{array}$	0.15
<i>Secondary</i>			<i>Tertiary</i>		
N-methyl-amylamine	$\begin{array}{c} \text{H} \\ \\ \text{C}-\text{N}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C} \end{array}$	0.25	triethylamine	$(\text{C}_2\text{H}_5)_3\text{N}$	0.07

Effect of Earth's Oblateness on the Period of a Satellite

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The effect of the earth's oblateness on the period of the latitudinal motion of a satellite in a near-circular orbit is investigated, and it is shown that in addition to the usual dependence on altitude the period depends as well on the inclination of the orbit to the equator. For orbits in the neighborhood of the equator, the period is less than for an orbit at the same height around a spherical earth. The period increases with orbit inclination, and for polar orbits the period is greater than for an orbit at the same height over a spherical earth. For a satellite at a height of 300 miles the difference in periods between polar and near-equatorial orbits is 12 sec.

Introduction

IF THE earth were a perfect sphere, the orbit of a satellite would be an ellipse with one focus at the center of the earth. The period of the satellite would depend only on its initial (launching or burnout) height and speed and is given by (1)²

$$T = \frac{2\pi GM}{\left(\frac{2GM}{r_0} - v_0^2\right)^{3/2}} = \frac{2\pi a^{3/2}}{(GM)^{1/2}} \dots\dots\dots [1]$$

where G is the universal constant of gravitation, M is the mass of the earth, r_0 is the initial distance of the satellite from the earth's center, v_0 is the initial speed, and a is the semi-major axis of the orbit. (Actually r_0 and v_0 in the above equation could be the distance and corresponding speed at any instant of time during the satellite's free flight.) For circular orbits ($GM = r_0 v_0^2$) the period reduces simply to

$$T_0 = \frac{2\pi GM}{v_0^3} = \frac{2\pi r_0}{v_0} = \frac{2\pi r_0^{3/2}}{(GM)^{1/2}} \dots\dots\dots [2]$$

The earth, however, is an oblate spheroid; and as a consequence thereof the satellite's orbit plane precesses around the polar axis (Fig. 1). For approximately circular³ orbits it has been shown (2) that the regression of the nodes⁴ per satellite revolution amounts to

$$\phi_r = 2\pi J (R/r_0)^2 \cos i = \frac{2\pi J \cos i}{\left(1 + \frac{h}{R}\right)^2} \dots\dots\dots [3]$$

where $J = 1.637 \times 10^{-3}$ is the coupling constant in the earth's gravitational potential (see below), i is the inclination of the orbit to the equator, R is the earth's equatorial radius, and $h = (r_0 - R)$ is the height of the (circular) orbit above the earth.

It is our aim now to investigate the effect of the earth's oblateness on the period of a satellite in a nearly circular orbit.

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² Numbers in parentheses indicate References at end of paper.
³ Strictly speaking, circular orbits are not possible over an oblate earth, except in the special case of the orbit plane coinciding with the equator. However, as shown in (2), in a near-circular orbit deviations from circularity are of the order of only 5 miles.
⁴ The points on the celestial sphere where the satellite crosses the equator are called the nodes.

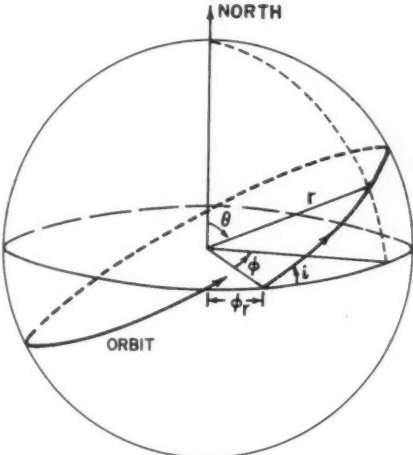


Fig. 1 Orbit showing nodal regression

Satellite Period

We describe the motion of the satellite after thrust termination by means of a nonrotating spherical polar coordinate system (r, θ, ϕ) with origin at the center of the earth (Fig. 1). It is assumed that the satellite is at sufficient altitude so that atmospheric drag is negligible and that the effects of gravitational anomalies and extraterrestrial bodies (sun, moon, planets) can be disregarded.

According to Jeffreys (3) the earth's oblateness may be described in terms of a latitude-dependent potential function

$$V(r, \theta) = -\frac{GM}{R} \left\{ \frac{R}{r} + J \frac{R^3}{r^3} \left(\frac{1}{3} - \cos^2 \theta \right) + \dots \right\} \dots\dots\dots [4]$$

The higher order terms in the potential function are sufficiently small that they may be neglected for present purposes. Since the potential is independent of azimuth ϕ , the angular momentum p about the polar axis is conserved.

$$p = r^2 \sin^2 \theta \dot{\phi} = \text{const.} \dots\dots\dots [5]$$

For simplicity we reckon time t and measure ϕ from the instant when the satellite is at the ascending node. Now it has been shown by Blitzer, Weisfeld and Wheelon (2) that in terms of the variable

$$x = \omega \phi = \left(1 + \frac{\phi_r}{2\pi}\right) \phi \dots\dots\dots [6]$$

the latitudinal motion is periodic in x , and to terms in first order in J is given by

$$\cot \theta = A \sin x + JS_1(x) \dots\dots\dots [7]$$

Here

$$A = \tan i \dots\dots\dots [8]$$

$$S_1(x) = (R/r_0)^2 \sin i \{ [\psi(x) - x] \cos x + (1 - \sec i) \sin x \} \dots [9]$$

and
$$\psi(x) = \arctan (\sqrt{1 + A^2} \tan x) \dots\dots\dots [10]$$

where one chooses the (principal value of the arctan) $+k\pi$ if $(2k-1)\pi/2 < x \leq (2k+1)\pi/2$.

The dependence of time on x can now be established with the aid of Equation [5]

$$t = \int \frac{r^2 \sin^2 \theta}{p} d\phi = \frac{r_0^2}{p} \int \frac{d\phi}{(1 + \cot^2 \theta)} \dots [11]$$

In setting $r = r_0 = \text{const}$ in [11] we are neglecting the possible effect on the period of the small variations of the orbit from circularity.

To terms up to the first order in J , then

$$\begin{aligned} t(x) &= \frac{r_0^2}{\omega p} \int_0^x \frac{dy}{1 + [A \sin y + JS_1(y)]^2} \\ &= \frac{r_0^2}{\omega p} \int_0^x \frac{dy}{1 + A^2 \sin^2 y} - \frac{2JA r_0^2}{\omega p} \int_0^x \frac{S_1(y) \sin y dy}{(1 + A^2 \sin^2 y)^2} \dots [12] \end{aligned}$$

Integrating, we find

$$\begin{aligned} t(x) &= \frac{r_0^2}{v_0} \psi(x) - \\ &J \frac{R^2 r_0}{r_0^2 v_0} \left\{ \left[\cos^2 i + \cos i \sin^2 i - \frac{1}{2} \sin^2 i \right] \psi(x) + \right. \\ &\quad \left. \frac{x - \psi(x)}{(1 + A^2 \sin^2 x)} + \frac{\sin^2 i (3 - 2 \cos i) \sin x \cos x}{2 \cos i (1 + A^2 \sin^2 x)} \right\} \dots [13] \end{aligned}$$

In observing the periodic motion of the satellite the simplest reference point to take is probably the node, or the equator. Therefore, we define the period as the time it takes the satellite to move from a node to the same node. This is, of course, the same as the period of the latitudinal motion.⁵ Hence the period (to terms in first order in J) is

$$\begin{aligned} T = t(2\pi) &= \frac{2\pi r_0}{v_0} - \frac{2\pi r_0}{v_0} J \frac{R^2}{r_0^2} \times \\ &\quad \left(\cos^2 i + \cos i \sin^2 i - \frac{1}{2} \sin^2 i \right) \dots [14] \end{aligned}$$

For $J = 0$ (spherical earth) the period is the same as in Equation [2], namely

$$T_0 = \frac{2\pi r_0}{v_0}$$

Hence we can write

$$T = T_0 \left[1 - J \frac{R^2}{r_0^2} \left(\cos^2 i + \cos i \sin^2 i - \frac{1}{2} \sin^2 i \right) \right] \dots [15]$$

For near-equatorial orbits ($i \ll \pi$)

$$T = T_0 \left(1 - J \frac{R^2}{r_0^2} \right) = T_0 \left[1 - \frac{J}{\left(1 + \frac{h}{R} \right)^2} \right] \dots [16]$$

and we observe that the period of a satellite in such an orbit is *less* than it would be around a spherical earth at the same distance r_0 .

For a polar orbit ($i = \pi/2$)

$$T = T_0 \left(1 + \frac{1}{2} J \frac{R^2}{r_0^2} \right) = T_0 \left[1 + \frac{J}{2 \left(1 + \frac{h}{R} \right)^2} \right] \dots [17]$$

and we observe that the period for a polar orbit is *greater* than it would be around a spherical earth at the same distance.

⁵ The astronomical parallel to the above definition of the period is the tropical year, which is the time it takes the sun to move from an equinox to the same equinox. This is the same as the period of the apparent latitudinal motion of the sun. The tropical year is the year as commonly reckoned.

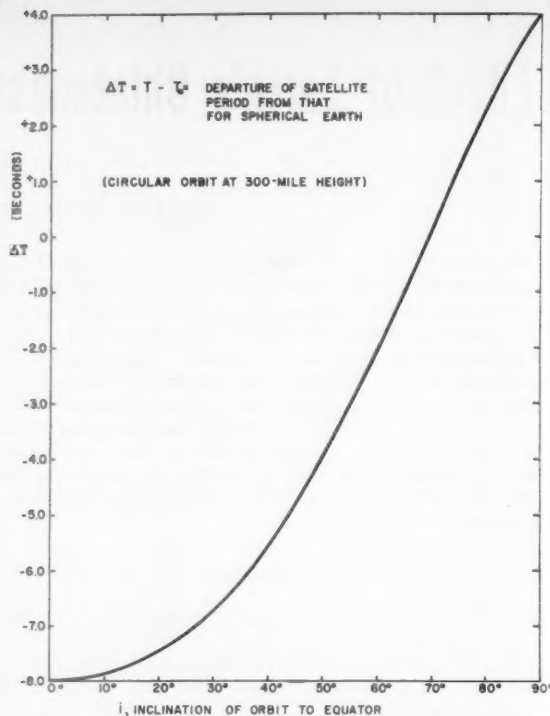


Fig. 2 Variation of satellite period with orbit inclination

At some intermediate orbit inclination the period of the satellite will be independent of the oblateness term in J . This will be when the trigonometric term in Equation [15] vanishes, and occurs for an orbit inclined at nearly 69 deg to the equator. In Fig. 2 we have plotted $\Delta T = (T - T_0)$, the departure of the period from T_0 , as a function of orbit inclination for a satellite at a height of 300 miles. In the extremes (equatorial-polar orbits) the periods differ by 12 sec.

Conclusion

It has been demonstrated that the period of an earth satellite in a near-circular orbit depends not only on its altitude but also on the inclination of the orbit to the equator. The fractional change in the period resulting from the earth's oblateness

$$\frac{\Delta T}{T_0} = -J \frac{R^2}{r_0^2} \left(\cos^2 i + \cos i \sin^2 i - \frac{1}{2} \sin^2 i \right) \dots [18]$$

indicates that the period for a satellite in a near-equatorial orbit is *less* than the period for an orbit at the same height around a spherical earth, while for polar orbits the period is *greater*.

This difference in the periods is not difficult to understand physically. For near-equatorial orbits ($i \ll \pi$, $\theta \doteq \pi/2$) at a fixed distance r_0 , the potential is constant and equal to

$$V = -\frac{GM}{r_0} \left(1 + \frac{JR^2}{3r_0^2} \right)$$

That is, the effect of the equatorial bulge is to increase the gravitational potential and hence the attractive force on the satellite. To maintain the fixed distance, the mean speed of the satellite must be increased and the period reduced. This reduction in period is also assisted by the nodal regression, because of our definition of the period as the time-interval between nodal crossings.

(Continued on page 397)

A Method for Calculating Impact Points of Ballistic Rockets

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A simple method is developed for determining impact points of ballistic rockets on a rotating earth. Rapid computation is facilitated by graphs giving time of flight between two chosen points of the elliptic trajectory. The method is applied to calculate the dispersion of an extreme high altitude unguided rocket.

Nomenclature

Ω	= angular rotation of the earth [rad·sec ⁻¹]
v_L	= launching velocity [m·sec ⁻¹], measured in a reference system which does not rotate with the earth
h_L	= altitude of launching point from surface of the earth [m]
a	= semimajor axis of orbit ellipse [m]
b	= semiminor axis of orbit ellipse [m]
e	= eccentricity of orbit ellipse [nondimensional]
\vec{r}	= radius vector from the origin O to the rocket [m]
\vec{r}	= component of total velocity parallel to the radius vector [m·sec ⁻¹]
$r\dot{\phi}$	= component of total velocity perpendicular to the radius [m·sec ⁻¹]
θ	= angle between the launching direction and the horizontal at $r = R_L$ [rad]
R_L	= distance of launching point from center of the earth [m]
R_E	= mean earth radius ($= 6.37 \times 10^6$) [m]
λ_L	= latitude of earth where rocket was launched [rad]
V_E	= velocity to the east due to rotation of the earth [m·sec ⁻¹]
$\Delta(P.E.)$	= change in potential energy of the rocket in going from a distance R_L to a distance r from the center of the earth [joules]
G	= Newton's gravitational constant ($= 6.67 \times 10^{-11}$) [nt·m ² ·kg ⁻²]
M_E	= mass of the earth ($= 5.98 \times 10^{24}$) [kg]
m	= mass of the rocket [kg]
A	= $(2GM_E/R_L) - v_L^2 \sin^2 \theta - v_L^2 \cos^2 \theta$ [joule kg ⁻¹]
B	= $2GM_E$ [nt·m ² ·kg ⁻¹]
C	= $R_L^2 v_L^2 \cos^2 \theta$ [m ⁴ ·sec ⁻²]
R_A	= apogee distance [m]
R_P	= perigee distance [m]
T_e	= period of the rocket in the complete ellipse [sec]
ϕ	= polar angle of orbit (i.e., geocentric angle) measured from perigee [rad]
A_f	= the fraction of the total area of the ellipse swept out by r in going from $\phi = 0$ (or $r/a = 1 - e$) to ϕ (or r/a) [nondimensional]
$A_f(\phi)$	= A_f in terms of ϕ [nondimensional]
$A_f(r/a)$	= A_f in terms of r/a [nondimensional]
$\phi(R_L)$	= the value of ϕ at the launching point [rad]
$\Delta\phi_E$	= the amount the earth has turned during the flight of the rocket [rad]
t	= total time of flight of the rocket [sec]
$\Delta\phi$	= the total angle r has turned through from $r = R_L$ on one side to $r = R_L$ on the other side of the ellipse in the flight of the rocket [rad]

d	= the distance on the surface of the earth that would be traversed by the rocket if the earth were not spinning [m]
λ_I	= latitude of point of impact [rad]
γ	= the angle between two lines on the surface of the earth at the launching point, one of these lines being simply from west to east. The other line is the intersection of the plane of the ellipse and the spherical surface of the earth. If the earth were not rotating this line would be obtained by projecting the launching velocity vector onto the surface of the earth at the launching point, but since the earth is rotating, we must add to the launching velocity vector as seen in the earth's system a vector to the east equal to the velocity of rotation of the earth's surface at the launching latitude. This gives us the launching velocity vector as seen from a coordinate system fixed in space, and it is this vector we wish to project onto the surface of the earth to give the second line defining γ [rad].

TWO methods may be used to calculate the impact point of a ballistic rocket. Although they lead to the same result, there are various conditions which will dictate which of the two methods is preferable.

The first method uses a coordinate system fixed with respect to the launching point and therefore rotating about the earth's axis with an angular velocity equal to the rotational speed of the earth. This method must make use of the well-known fictional forces, principally the Coriolis force $\vec{\Omega} \times \vec{v}$, and since \vec{v} in general varies with time, the method can become quite tedious.

The purpose of this paper is to describe the second method which uses a reference system which is fixed with respect to the stars and in which the rotation of the earth is taken into account (a) by giving the rocket at burnout a horizontal velocity component equal to the earth's surface speed due to its rotation, and (b) by finding the impact point (in the fixed coordinate system), calculating the time of flight of the rocket, and calculating therefore how far the earth has turned while the rocket has described its trajectory.

It is well known that objects in an inverse square field of force describe elliptic orbits. In the case of rockets fired from the surface of the earth, however, the motion is obviously not cyclic. But if all the mass of the earth were concentrated at its center,³ the rocket would follow an elliptic trajectory, and the properties of the motion of the rocket above the earth are conveniently calculated in terms of this ellipse.

The initial conditions, i.e., the launching velocity v_L and height h_L , completely determine the ellipse which will always have one focus at the center of the earth (Fig. 1). We assume that burnout occurs well above the atmosphere so there is no frictional drag on the rocket in its subsequent motion until it returns and falls through the atmosphere. Since we are in an inertial reference frame, the initial velocity v_L is the sum of the burnout velocity in the earth's frame of reference and the velocity to the east due to the rotation of the earth. Once we have the ellipse from the initial conditions, we can calcu-

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³ An assumption which neglects the small nonsphericity of the earth.

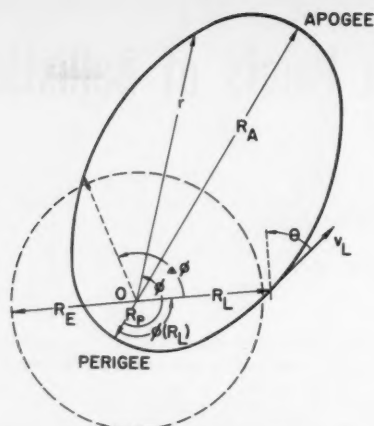


Fig. 1 The elliptic orbit of a ballistic rocket showing notation used

late where the rocket returns at an earth's radius from the focus of the ellipse. Then, taking into account the fact that the earth has rotated under the rocket while it was describing its orbit, we will have the impact point.

With this end in view, we will derive convenient nondimensional expressions giving the time between two points in an elliptic orbit as a function of eccentricity and size of the ellipse. We make use of the fact that in an elliptic orbit a particle will trace out equal areas in equal intervals of time, i.e., with a constant areal velocity. Since we know the period of the orbit in terms of the parameters of the ellipse, for example, the eccentricity and semimajor axis, from Kepler's third law, all we need to find is the fractional area between any two points of the ellipse. This will then give us directly the fraction of the period spent in travelling between the two points. We know of course that the total area of the ellipse is $\pi ab = \pi a^2(1 - \epsilon^2)^{1/2}$.

Derivations

Fig. 1 is a diagram of the elliptical orbit a rocket would follow after burnout if all the mass of the earth were concentrated at its center O . At any point in its orbit, the velocity of the rocket can be resolved into two components, a velocity \dot{r} parallel to \vec{r} , and a velocity $r\dot{\phi}$ perpendicular to \vec{r} , where \vec{r} is the radius vector from the origin. The initial conditions for this elliptical orbit are $v_L \sin \theta$, $v_L \cos \theta$, and R_L where R_L is the distance from the origin O , or center of the earth, to the point above the surface of the earth where final burnout has just been completed; $v_L \sin \theta$ is the vertical velocity in the frame of reference of the earth just after burnout; and $v_L \cos \theta$ is the vector sum of the horizontal velocity in the frame of reference of the earth just after burnout plus the velocity due to the rotation of the earth to the east. We assume that R_L is very nearly equal to the radius of the earth R_E , so that the velocity due to the rotation of the earth is a function of the latitude λ_L where the rocket was fired, and is given by

$$V_E = 2\pi R_E \cos \lambda_L / (3600 \times 24) = 465 \cos \lambda_L [\text{m/sec}] \quad [1]$$

The rocket gains potential energy $\Delta(P.E.)$ and loses kinetic energy in going from a distance R_L to a distance r from the center of the earth, where

$$\Delta(P.E.) = \int_{R_L}^r (GM_E m / r^2) dr = GM_E m (R_L^{-1} - r^{-1}) \quad [2]$$

Since angular momentum $\vec{r} \times \vec{v}$ is conserved in a purely central force field, we have $\vec{r} \times \vec{v}$ evaluated at R_L equal to $\vec{r} \times \vec{v}$ evaluated at the general r , and we thus have

$$R_L v_L \cos \theta = r \times r \dot{\phi} = r^2 \dot{\phi} \quad [3]$$

Furthermore, from conservation of energy we have the kinetic energy $\frac{1}{2}mv^2$ evaluated at R_L equal to the sum of the kinetic energy evaluated at r plus the gain in potential energy $\Delta(P.E.)$, and this reduces to

$$\frac{1}{2}m(v_L^2 \sin^2 \theta + v_L^2 \cos^2 \theta) = \frac{1}{2}m(\dot{r}^2 + R_L^2 v_L^2 \cos^2 \theta / r^2) + GM_E m (R_L^{-1} - r^{-1}) \quad [4]$$

From [4] we may obtain

$$\dot{r}^2 = v_L^2 \sin^2 \theta + v_L^2 \cos^2 \theta - 2GM_E / R_L + 2GM_E / r - R_L^2 v_L^2 \cos^2 \theta / r^2 \quad [5]$$

Let us now define the quantities

$$\begin{aligned} A &= 2GM_E / R_L - v_L^2 \sin^2 \theta - v_L^2 \cos^2 \theta \\ B &= 2GM_E \\ C &= R_L^2 v_L^2 \cos^2 \theta \end{aligned} \quad [6]$$

Now, at the apogee and perigee of the ellipse we have $\dot{r} = 0$ since the rocket is not moving toward or away from the earth at these two points (see Fig. 1); so that from [5] and [6]

$$-AR_A^2 + BR_A - C = 0 \quad -AR_P^2 + BR_P - C = 0 \quad [7]$$

and from [7] we find

$$\begin{aligned} R_A &= B(1 + [1 - 4AC/B^2]^{1/2})/2A \sim B/A \text{ for } 4AC/B^2 \ll 1 \\ R_P &= B(1 - [1 - 4AC/B^2]^{1/2})/2A \sim C/B \text{ for } 4AC/B^2 \ll 1 \end{aligned} \quad [8]$$

The ellipse is completely determined by R_A and R_P . For the ellipse shown in Fig. 2, we have the well-known relations

$$\begin{aligned} (x^2/a^2) + (y^2/b^2) &= 1, \quad \epsilon = (1 - b^2/a^2)^{1/2} \\ r &= a(1 - \epsilon^2)/(1 + \epsilon \cos \phi) \end{aligned} \quad [9]$$

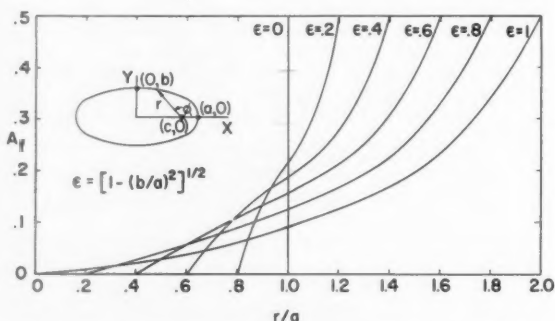


Fig. 2 The fraction of the area of an ellipse A_f swept out by the radius vector in moving between $r = a - c$ and r , plotted as a function of r/a

From [8] and [9] therefore, we derive the eccentricity, semi-major axis and period

$$\epsilon = (R_A - R_P)/(R_A + R_P) = (1 - 4AC/B^2)^{1/2} \sim 1 - 2AC/B^2 \text{ for } 4AC/B^2 \ll 1 \quad [10]$$

$$a = (R_A + R_P)/2 = B/2A \quad [11]$$

$$T_e = 2\pi(GM_E)^{-1/2} a^{3/2} \quad [12]$$

We now consider the useful property that, for the motion of the rocket in this ellipse, equal areas are swept out in equal times. Therefore, if we know the fraction of the total area of the ellipse $A_f(\phi)$ swept out by r going from $\phi = 0$ to ϕ , the time taken in this motion would be $T_e \times A_f(\phi)$. From this consideration, it is evident that the time for the rocket to travel from $r = R_L$ on one side of the ellipse to $r = R_L$ on the other side is

$$t = [1 - 2A_f(\phi(R_L))] \times T_e \quad [13]$$

Now A_f is plotted as a function of ϕ in Fig. 3 and as a function of r/a in Fig. 2. Fig. 2 is most useful for $\epsilon \sim 1$, while

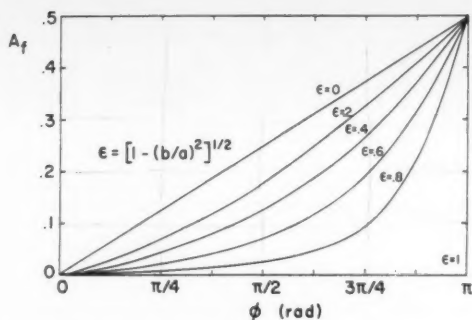


Fig. 3 The fraction of the area of an ellipse A_f swept out by the radius vector in moving between $\phi = 0$ and ϕ , plotted as a function of ϕ

Fig. 3 is most useful for $\epsilon \sim 0$. The fraction of the area of the ellipse contained between $\phi = 0$ and ϕ is⁴

$$A_f(\phi) = \frac{1}{2\pi ab} \int_{\phi'=0}^{\phi'= \phi} r^2 d\phi' = \frac{(1-\epsilon^2)^{1/2}}{2\pi} \left(-\frac{\epsilon \sin \phi}{1+\epsilon \cos \phi} + \frac{2}{(1-\epsilon^2)^{1/2}} \tan^{-1} \left[\frac{(1-\epsilon^2)^{1/2}}{\tan^{1/2} \phi (1+\epsilon)} \right] \right) \quad [14]$$

and the fraction of the area of the ellipse contained between $r/a = 1 - \epsilon$ ($\phi = 0$), and r/a is

$$A_f(r/a) = \frac{1}{2\pi} \sin^{-1} [(-1 + r/a)/\epsilon] - \frac{\epsilon}{2\pi} [1 - (-1 + r/a)^2/\epsilon^2]^{1/2} + 1/4 \dots [15]$$

Once we have computed the time taken by the rocket in its trajectory, we can compute the amount the earth has turned during time t from

$$\Delta\phi_E = 7.26 \times 10^{-5} \dots [16]$$

where $7.26 \times 10^{-5} \text{ rad sec}^{-1}$ is the earth's rotational velocity.

We finally also need to calculate the change in ϕ from one side to the other for the rise and fall of the rocket, and for this we need $\phi(R_L)$ where $\cos \phi$ is given in [9], and, also from [10], we have

$$\phi(R_L) = \cos^{-1} [(-1 + 2C/R_L B)/\epsilon] \sim \frac{1}{2\pi} (1 \pm 1) \pm (2[1 \mp \cos \phi(R_L)])^{1/2} \text{ for } \cos \phi(R_L) \sim \pm 1 \dots [17]$$

and

$$\Delta\phi = 2(\pi - \phi(R_L)) \dots [18]$$

The change in latitude between the launching latitude λ_L and the point of impact latitude λ_I can then be calculated by Napier's rule in spherical trigonometry⁵

⁴ See Pierce, "Tables of Integrals," integral #305.

⁵ The authors would like to thank at this point the anonymous reviewer of this paper for suggesting the use of Napier's rule. We had not originally made use of this rule in the first draft of this paper, and we consider that its application puts these final crucial calculations in a particularly elegant form.

⁶ Obviously, if the rocket is not an extremely high altitude device, it may not be necessary to take into account the rotation of the earth, and other more simple methods are available for the calculations of impact points. This paper may also be applied to this case by neglecting the velocity to the east due to the rotation of the earth, and also neglecting the rotation of the earth below the rocket during its time of flight.

$$\lambda_I - \lambda_L = \sin^{-1} (\sin \Delta\phi \sin \gamma) \dots [19]$$

where γ is defined in the Nomenclature.

The change in longitude between the launching longitude and the point of impact longitude can be similarly calculated, but in this case the earth has rotated through an angle $\Delta\phi_E$ during the time of flight of the rocket, and this angle must therefore be subtracted off if we are considering a positive change in longitude as being one in which the point of impact is to the east of the launching point. Therefore, we have

$$\Delta(\text{longitude}) = \sin^{-1} (\sin \Delta\phi \cos \gamma) - \Delta\phi_E \dots [20]$$

A sample calculation is made in the Appendix for a rocket having a burnout velocity of 7.7 km/sec^{-1} at an altitude of 30 km at the equator, and for firing in the vertical direction and with 5 deg dispersion to the east, west, north, and south. The results are shown in Fig. 4.⁶

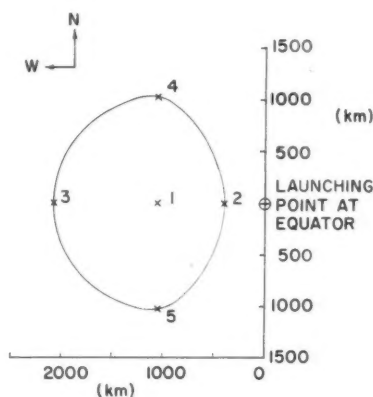


Fig. 4 Dispersion due to earth's rotation points of impact for a ballistic rocket fired at the equator with initial velocity 7.7 km/sec : 1) vertically; 2) 5° to east; 3) 5° to west; 4) 5° to north; 5) 5° to south

APPENDIX

Sample Calculation

For a rocket fired vertically at the equator the following data apply:

$$v_L \sin \theta = 7.7 \text{ km/sec}^{-1} \text{ (burnout velocity with respect to launcher)}$$

$$v_L \cos \theta = 0.465 \text{ km/sec}^{-1} \text{ (earth rotational velocity)}$$

A , B , and C can now be calculated from Equation [6].

Using [10] we get the eccentricity $\epsilon = 0.9982$.

Using [11] we get the semimajor axis $a = 6145 \text{ km}$.

Using [12] the complete period of the ellipse is $T_e = 4840 \text{ sec}$.

From Fig. 2 or 3, as the case may be, (here, since $\epsilon \sim 1$ we use

Fig. 2) the fractional area of the ellipse swept out between burnout and peak is 0.401. Therefore the time to peak is $0.401 \times 4840 = 1940 \text{ sec}$; the total time of flight is 3880 sec.

During this time the earth (and the launcher) has turned through $7.26 \times 10^{-5} \times 3880 = 0.282 \text{ rad}$ (the angular velocity of the earth being $7.26 \times 10^{-5} \text{ rad/sec}^{-1}$).

Using $R_L = 6.4 \times 10^6 \text{ m}$, and [9], we compute $\cos \phi(R_L) = -0.9983$. Then from [17, 18] we find that the geometric angle $\Delta\phi$ swept out in the elliptic trajectory is 0.117 rad so that the launcher is $0.282 - 0.117 = 0.165 \text{ rad}$ ahead (to the east) of the impact. The distance is 1057 km.

The Flight Path of an Electrically Propelled Space Ship¹

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The present study deals with the flight phases which are necessary and sufficient to achieve an expedition to Mars and back with a low-thrust, electrically propelled space ship (Ref. 1). Trajectory calculations were made in a simplified manner. Although no optimization has been attempted, the results show that flight times and required maneuvers are well within the limits of feasibility. The trip to Mars takes 401 days, stay time on Mars is 472 days, and the trip back to earth lasts 311 days. Corrective maneuvers may require a few additional days. The problems of navigation can be solved with conventional methods.

Nomenclature

G	= gravitational force of earth at earth's surface
g_r	= gravitational force of earth at distance r from center
F	= thrust force of electrical propulsion system
r_0	= radius of earth satellite orbit
r	= distance from center of earth
ρ	= radius of earth
v	= velocity of ship in earth-fixed coordinate system
φ	= angular distance between ship and reference line
M	= mass of ship at take-off
M_t	= mass of ship at time t
γ	= gravitational constant
μ	= mass of earth
t	= time
τ	= time for one orbital revolution

Introduction

THE flight mechanics of a space ship with electrical propulsion system differ principally from that of a space vehicle powered by chemical reaction motors. The acceleration of an electrical space ship is only a small fraction of one G . Propellant consumption and mass ratio are smaller than in a chemically powered ship. The time of propulsion is much longer; in fact, the electrical propulsion system works almost during the entire trip, either accelerating or decelerating. Except for a few powerless periods of short duration, which are needed for corrective maneuvers, the electrical ship's trajectory will not follow an elliptical path, but segments of spirals.

The constant application of power enables the crew to make adjustments and corrections during the entire trip. Navigation of an electrical ship is therefore much simpler than navigation of a chemical ship with its short propulsion periods and very long free-coasting intervals. At no time during the entire trip of an electrical ship is there a need for extreme precision of maneuvers. The weights of components and payload, the duration of individual phases of the flight, and even the performance of the propulsion system may vary considerably during flight without endangering the safe completion of an interplanetary expedition.

The inherently small acceleration of an electrical space ship

makes a take-off from the earth or any other planet impossible. An electrically propelled vehicle will therefore always start and end its trip in a satellite orbit where it can stay weightlessly and without power for any desired length of time.

Mathematical Approach

A number of papers have been published which deal with interplanetary trajectories of slowly accelerating vehicles (2).³ In the present study, no emphasis has been placed on minimization of energy or time of the trajectory, or on other details of trajectory calculations. Rather coarse methods were applied to compute the individual phases of a flight path. Instead, an attempt has been made to work out a complete flight plan which describes the maneuvers necessary to take the ship from an earth orbit to an orbit 1000 km above the surface of Mars, and from there back to the earth orbit. Even without elaborating on refinements, results indicate that a round trip earth-Mars-earth with an electrical space ship is possible within a reasonable travel time, without high accuracy requirements and with moderate navigational means.

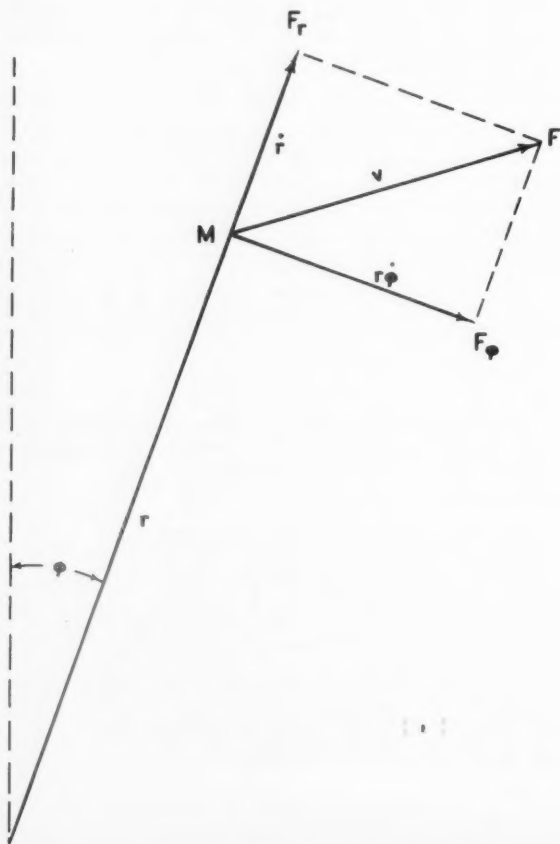


Fig. 1 Designation of forces acting upon space ship

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¹ Statements and opinions advanced in this paper are to be understood as individual expressions of the author and do not necessarily reflect the views and opinions of the Army Ballistic Missile Agency.

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³ Numbers in parentheses indicate References at end of paper.

The following simplifications were used:

1 Earth and Mars move on concentric circles around the sun within the same plane.

2 The ship's motion is always treated as a two-body problem (earth-ship; sun-ship; Mars-ship).

3 The thrust of the propulsion system is constant. The propellant mass decreases linearly with propulsion time; the rest of the ship's mass is constant.

4 The thrust vector is tangential to the trajectory, except in short maneuvers, where the thrust assumes directions as indicated in Figs. 4 and 5.

The motion of the space ship is determined by the thrust force and the laws of mechanics. Referring to Fig. 1, we obtain

$$F_r - M_g r + M_i r \dot{\varphi}^2 - M_i \ddot{r} = 0 \dots \dots \dots [1]$$

$$F_{\varphi} - \frac{d}{dt} (M_i r^2 \dot{\varphi}) = 0 \dots \dots \dots [2]$$

Equation [1] expresses equilibrium between thrust, gravitational force, centrifugal force and inertial force. Equation [2] is the momentum equation. Rearranging terms, and substituting

$$F_r = F \frac{\dot{r}}{v} \quad v = \sqrt{\dot{r}^2 + r^2 \dot{\varphi}^2}$$

$$F_{\varphi} = F \frac{r \dot{\varphi}}{v} \quad g_r = g_0 \frac{\rho^2}{r^2}$$

we obtain

$$\ddot{r} = F \frac{\dot{r}}{M_i \sqrt{\dot{r}^2 + r^2 \dot{\varphi}^2}} - G \frac{\rho^2}{r^2} + r \dot{\varphi}^2 \dots \dots \dots [3]$$

$$\ddot{\varphi} = F \frac{\dot{\varphi}}{M_i \sqrt{\dot{r}^2 + r^2 \dot{\varphi}^2}} - 2 \frac{\dot{r} \dot{\varphi}}{r} \dots \dots \dots [4]$$

These equations lend themselves easily to stepwise integration [3] with the initial conditions

$$r(0) = r_0 \quad \varphi(0) = 0$$

$$\dot{r}(0) = 0 \quad \dot{\varphi}(0) = \sqrt{\mu \gamma / r_0^3} = 0.05^\circ / \text{sec}$$

$$\dot{M}(0) = M$$

The ship's trajectory, after detaching from the satellite's orbit, begins with a narrow spiral. Instead of computing this spiral by integrating [3 and 4], a simpler and faster method was applied. Replacing one revolution of the spiral by a circle, we may express the total energy gained on this circle by

$$\Delta E = F \Delta s = F 2 \pi r \dots \dots \dots [5]$$

The total kinetic plus potential energy of the ship on this circle is

$$E = E_{\text{kin}} + E_{\text{pot}} = \frac{1}{2} M_i g_r r$$

hence

$$\Delta E = \frac{1}{2} M_i g_r \Delta r \dots \dots \dots [6]$$

Equating [5] and [6] yields

$$\Delta r = \frac{4 \pi r F}{M_i g_r}$$

or

$$\Delta r = F \frac{4 \pi}{M_i \mu \gamma} r^3 \dots \dots \dots [7]$$

as the incremental distance from the center of the earth gained with one revolution. The time for one revolution of

the spiral may be approximated by the orbiting time on a circle with a radius equal to the average radius of the spiral

$$\tau_r = 2 \pi \sqrt{r^3 / \mu \gamma} \dots \dots \dots [8]$$

With [7 and 8] the spiral trajectory of the ship may be quickly computed. When the spiral becomes wider, this method loses accuracy. Equations [5 and 6] are then applied with the initial conditions

$$\dot{r}(0) = \frac{\Delta r}{\tau_r} = \frac{2 F}{M_i} \sqrt{\frac{r^3}{\mu \gamma}}$$

and

$$\dot{\varphi}(0) = \sqrt{\frac{\mu \gamma}{r^3}}$$

If the ship accelerated constantly, it would after some time cross the Martian ellipse, but it would never be able to enter into a stable orbit around Mars. Even if it approached close by the planet, its trajectory would be deflected into a hyperbola only. For that reason, the ship must undergo deceleration maneuvers before approaching the Martian ellipse.

The lengths of the accelerating and decelerating phases of the earth-Mars trip were found by a trial and error method. A number of trajectories with variation of switch-over points were computed, until a sequence of maneuvers had been found which met with the following conditions:

1 Disregarding the Martian attraction, the ship must approach the Martian ellipse on an elliptical trajectory. Closest distance between the two elliptical paths must be not more than 10^6 km, and not less than 0.5×10^6 km.

2 The ship must approach the Martian ellipse at a time when Mars is there too. Ideal relative positions of Mars and ship over a period of a few weeks are shown in Fig. 4.

Vehicle and Trajectory Data

The dimensions and performance data of a representative space ship are given in (lb). Some of the essential data are listed here in Table 1.

Table 1 Design and performance data of electrical space ship

Total initial mass	730 tons
Total propellant mass	365 tons
Propellant consumption	5.8 g sec ⁻¹
Voltage	4880 volts
Current	4220 amps
Exhaust velocity	84 km sec ⁻¹
Thrust	50 kg
Initial acceleration	$0.67 \times 10^{-4} G$
Payload	150 tons

With these data, the following phases of the flight path are found.

Phase 1—Spiral Around Earth

The ship leaves the satellite station when Mars has a relative position as shown in Fig. 3. After 2 hours, the satellite has completed one revolution. The ship will be 11 km out and 35 km in the rear of the satellite. After 60 hours, the satellite has made 30 revolutions; the ship, exactly 29. The distance from ship to satellite is 342 km. After 107 days, the ship is 177,000 km beyond the satellite orbit (185,000 km from the center of the earth) and about halfway between earth and moon. At that time, it has made 377 revolutions around the earth (Fig. 2). The ship is now not far from the point where its total energy is equal to that of a body falling from infinity to that point. It is designated

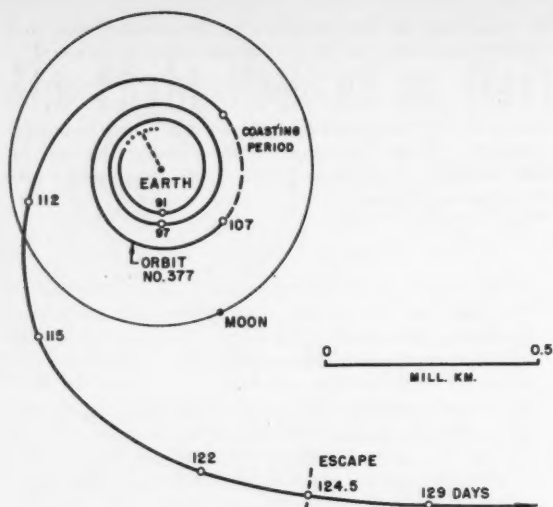


Fig. 2 Spiral trajectory of space ship around earth

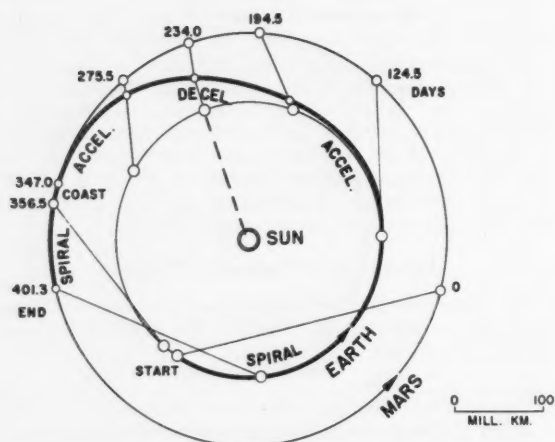


Fig. 3 Trajectory of space ship between earth and Mars

"escape" in Fig. 2. If the ship's propulsion system were shut down before reaching this point, the ship would continue to circle around the earth in an ellipse. If the thrust were cut off after this point, the ship would leave the earth's gravitational field on a hyperbolic trajectory leading into a solar ellipse. Before arriving at this "point of escape," the ship makes a corrective maneuver. As Fig. 3 shows, the direction of the escape leg must be such that it leads smoothly into a spiral trajectory around the sun. Since the earth spiral probably will not lead directly into this escape leg, the ship inserts a period of powerless flight on which its radial distance from the earth and its velocity remain constant; only its angular position varies. By cutting off its thrust slowly, it changes the spiral trajectory into a circular one. As soon as the correct position is reached, the thrust is switched on again and the ship continues to spiral out (Fig. 2).

As shown in Fig. 2, the ship will come no closer to the moon than about 180,000 km if the expedition is timed properly. Gravitational forces between moon and ship at that distance are such that their influence on the trajectory can be corrected with the available thrust.

It will be noticed from Equation [7] that the slope of the spiral depends very sensitively on the acceleration of the ship. Even a small increase of the thrust means a considerable reduction of the spiraling time from take-off until escape.

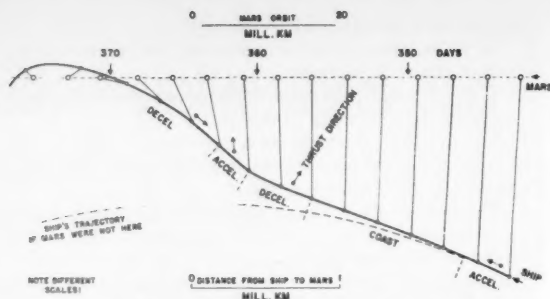


Fig. 4 Approach of space ship to Mars as seen from sun

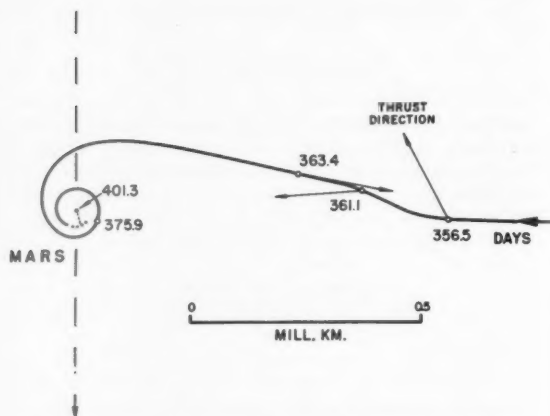


Fig. 5 Approach of space ship to Mars as seen from Mars

Phase 2—Trajectory Around Sun

From the point of escape on, the ship was considered to be subject to the solar gravitation field only. Equations [3 and 4], which had been used from the 100th day on (Fig. 2) with respect to the earth, are applicable to the ship's motion in the solar field, when the earth's data are exchanged against the sun's data. The ensuing trajectory is shown in Fig. 3. At first, the ship's path follows the earth's ellipse rather closely. As the ship gains speed, its trajectory gradually detaches from the earth's ellipse. On the 194th day, the thrust direction is reversed by 180 deg. The ship decelerates and its trajectory bends slowly inward. On the 234th day, the earth passes between ship and sun, because its angular speed with respect to the sun has become greater than that of the ship. The apparent size of the earth, as seen from the ship, is 1.18 min of arc; that of the sun, 25.6 min; and that of Mars, 0.596 min. If the earth passed through the diameter of the sun, the passage would take 22.5 min of time. However, the earth will not pass through the middle of the solar disk, and possibly not even through the disk at all, because the ecliptics of earth and Mars are not within the same plane. The decelerating period lasts 81 days. On the 275th day, the thrust is reversed again. The acceleration of the ship bends the trajectory outward so that it approaches the Martian ellipse tangentially. On the 347th day, the ship's trajectory is about 1.6×10^6 km inside the Martian ellipse. The thrust is cut off and the ship coasts on a solar ellipse which takes it closer to the Martian ellipse (Fig. 4). The velocity of the ship is smaller than that of Mars. Therefore, the ship continues to coast around the sun on an ellipse which has a smaller minor axis than the ellipse of Mars (Fig. 4), unless Mars approaches from the rear and captures the ship into its own gravitational field. If properly timed, the ship follows a trajectory as shown in Figs. 4 and 5. If the timing is not correct and the ship does not meet Mars at the proper place, a corrective maneuver must be inserted.

Phase 3—Corrective Maneuvers in Martian Ellipse

If the ship should arrive in the Martian ellipse too early, it directs its thrust rearward, thereby slowing down its velocity. In order to prevent its transition into an inward spiral around the sun, it turns its thrust direction slowly away from the sun, thus compensating the sun's attractive force. If that maneuver were continued long enough, the thrust would finally push in a radial direction and the ship would move on the Martian ellipse with only one-half of Mars' velocity. The time needed to complete this maneuver would be of the order of one year. In a practical case, it would not be necessary to reduce the ship's velocity to one-half of Mars' speed. The small corrections normally needed could be carried out within a few days.

If the ship should arrive in the Martian ellipse too late, it would direct its thrust forward and then slowly toward the sun. In this way it would increase its velocity and still stay on the Martian ellipse until captured by the planet.

Phase 4—Approach to Mars

The various maneuvers needed to approach Mars correctly are shown in Figs. 4 and 5. In Fig. 4, the motions of the ship and Mars are seen from a point fixed to the sun. In Fig. 5, the motion of the ship is depicted as seen from Mars. After a free-coasting period of about 12 days, the thrust is applied under such an angle that the ship is forced closer to Mars, but also to the side, in order to lead the ship into a spiral around the planet. Without this lateral thrust component, the ship would finally fall straight toward Mars. Five days later, the thrust is directed toward Mars. After another two and one-half days, the thrust is reversed. It acts from now on tangentially as a pure braking force.

These maneuvers have been selected in such a way that the ship gradually enters into a spiral of descent around the planet (Fig. 5). The trajectory was computed with Equations [3 and 4], referred to Mars instead of the earth. From the 376th day on, Equations [7 and 8], which apply to a narrow spiral, were again used. On the 401st day, the ship is on an almost circular orbit, 1000 km above the surface of Mars. The thrust is cut off and exploration of the planet can begin.

Phase 5—Stay Time in Martian Orbit

The time which the ship will spend in the Martian orbit is determined by the relative positions of Mars and earth. Fig. 6 shows the positions required for the return trip. The time from the ship's arrival on Mars to the moment when Mars and earth have the proper position is 472 days, or roughly two-thirds of one Martian year. This time appears adequate for

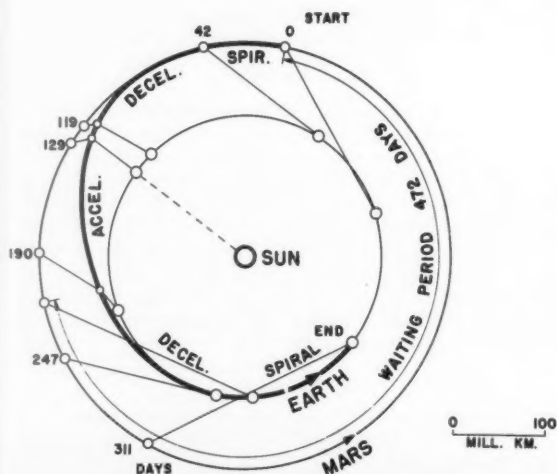


Fig. 6 Return trip from Mars to earth

explorations on Mars. Descent from the space ship to the Martian surface will be made by special landing craft carried on the space ship. Ascent from Mars to the space ship will be made by a one-stage rocket with chemical propulsion system; this rocket is a part of the landing craft (4).

Phase 6—Return Trip

The time of departure from the Martian orbit can be determined only when the travel time from Mars to earth is known. The various phases of the return trip were calculated in a fashion very similar to those of the trip to Mars. The durations of these phases are shorter than on the way out because the ship has become lighter. The spiraling around Mars until escape takes 42 days. On the 129th day after take-off from Mars, the earth again passes between ship and sun. This time, the earth appears under an angle of 0.72 min of arc; Mars, under 1.03 min; and the sun, under 22.6 min. If the earth passed through a diameter of the sun, it would take 12.7 min of time for the passage. On the 190th day, the thrust is again reversed for deceleration. The ship is captured in the earth's gravitational field on the 247th day after a few short maneuvers similar to those leading to capture within the Martian gravitational field. From then on, spiraling begins around the earth. On the 311th day after take-off from Mars, the ship arrives in the 1700 km satellite orbit around the earth, after a total time of absence of three years and 89 days. This period does not include several days for corrective maneuvers. If the payload on the return trip is smaller than on the way out, the travel time for the return trip will be shorter.

Navigational System

Navigation of a low-thrust space ship is relatively simple, since no extreme accuracies are needed at any instant of the flight. The basic idea of the navigational system is the following: The ideal trajectory of the ship is calculated before the flight begins, including all the phases of acceleration and deceleration. This calculation is based on a thrust figure which is somewhat lower than the maximum available thrust. The data of the precalculated trajectory, in the form of x , y , and z coordinates as functions of time, are presented continuously on board the ship. Also, the instantaneous location of the ship is continuously measured by taking optical bearings to fixed stars and planets; the exact positions of the latter are known at every instant from astronomical tables. By comparing the precalculated coordinates with the measured values, any deviation of the ship from its predetermined path will be recognized immediately and can be corrected.

Three different coordinate systems are used. The first has its center in the earth. It moves with the earth, but does not follow its rotation. The ship's motion is precalculated and also measured in this system from take-off until escape. The second system has its center in the sun. The fixed stars will retain fixed positions in this system. The third system has its center in Mars. It moves with Mars, but does not follow its axial rotation. The third system will be used from capture in the Martian gravitational field until the stable orbit around Mars has been reached.

The ship carries a set of star seekers which remain aligned with remote fixed stars. This set represents the reference frame for each of the coordinate systems. In principle, two fixed stars would be sufficient to fix the reference frame. However, the earth, the sun, the moon, or Mars may obstruct temporarily the line of sight to a fixed star. Therefore, five different stars and five star seekers will be used at all times (Fig. 7). As an example, the fixed stars Regulus, Antares, Formalhaut, Aldebaran and Vega may be selected. In addition to these fixed seekers, five more seekers will be used which look toward the sun, the earth, Mars, Venus, and Jupiter. Each of them can turn around two axes (Fig. 7). The

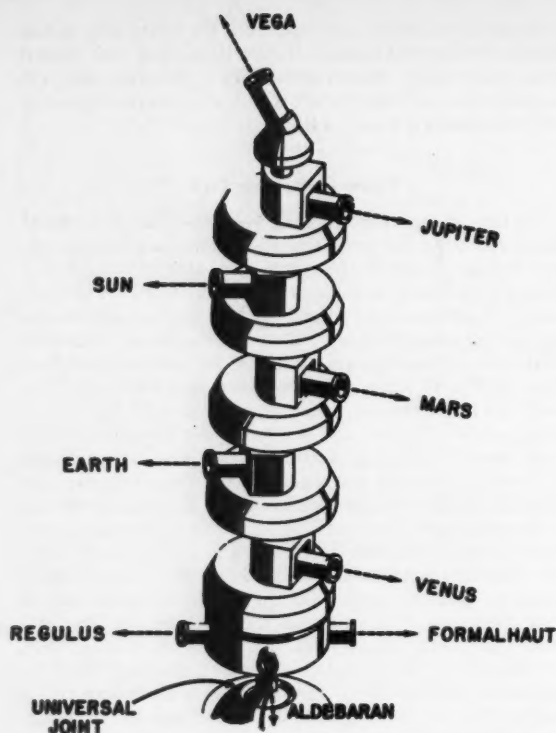


Fig. 7 Arrangement of planet and star seekers for astronavigation

angular rotations of these two axes are read in analog and in digital form. Another triplet of seekers is directed such that the seekers align with the circumference of the earth and later with that of Mars, at three evenly spaced points. By measuring the angle subtended by the earth or Mars, the distance between the ship and the planet can be calculated.

Three display boards will be used on board the ship for quick reference. The first one has the earth in its center; the second, the sun; the third, Mars. Analog signals from the planet seekers are fed into the display boards. The first one will display the ship-to-earth distance and the angle between the reference direction and the ship-earth line. The spiral trajectory of the ship will thus be gradually recorded on this board.

Digital readings of distance and direction will be fed simultaneously into a digital computer for more accurate calculations of ship coordinates in x , y , and z . The results are constantly compared with precalculated values. If deviations occur, the ship's trajectory is corrected by variations of thrust or thrust direction.

When the ship is on its solar path, the readings of the planet directions are fed into the second display board which has the sun in its center. This board contains the planets Venus, earth, Mars, and Jupiter, moving on their scaled-down ellipses in real time. The angles between the reference direction and the direction to each of the planets as read by the seekers on the ship are equal to the angles which would be read on the planets between the reference direction and the direction to the ship (Fig. 8). Therefore, when these angles are plotted from the reference direction on the board with their vertices in the planets, all the lines will intersect in one point which is the instantaneous location of the ship (Fig. 9). In this manner, the trajectory of the ship can be continuously recorded and checked for correctness. At the same time, the angular readings from the seekers are fed in digital form into a computer which contains the position data of the planets in the form of preset programs. It continuously calculates the ship's position in three dimensions. The results are again compared with precalculated values of the desired

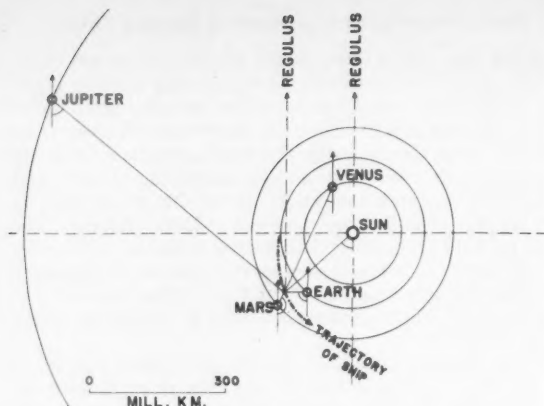


Fig. 8 Reference system for astronavigation

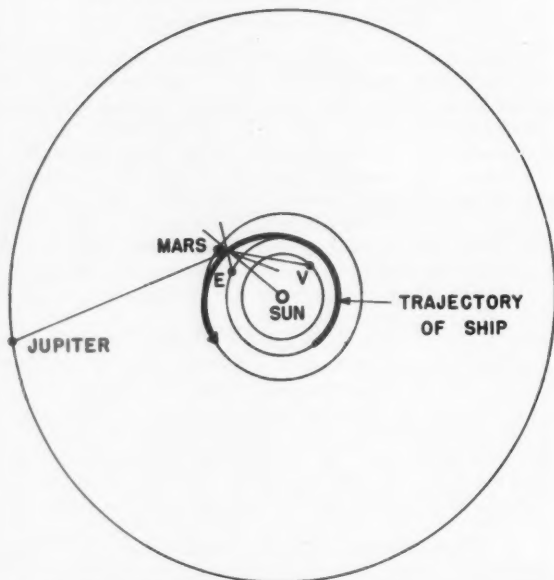


Fig. 9 Display board of planets' and ship's instantaneous locations

trajectory. If necessary, corrections are applied to the ship. Navigation around Mars will be similar to that around the earth. While the ship is very close to the earth or to Mars, direct distance measurements are made either by radar methods or, while distances are between 10,000 and 100,000 km, by measuring the angle subtended by the planet.

Conclusions

Even without optimization of the trajectory, a round trip to Mars appears feasible with a slowly accelerating, electrically propelled space ship. Corrective maneuvers can be carried out with the electrical propulsion system. No auxiliary chemical powerplants will be necessary. The navigation equipment consists of a time piece, a number of star and planet seekers, display boards for quick reference and digital computers which calculate the ship's position continuously in three dimensions from star bearings. A radar set and an angle-measuring seeker triplet will measure close distances between ship and Mars or earth.

References

- 1 a. Stuhlinger, E., "Possibilities of Electrical Space Ship Propulsion," Fifth International Astronautical Congress, Innsbruck, Austria, 1954.

(Continued on page 397)

Technical Notes

On the Optimization of Two-Stage Rockets

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Equations useful in design studies are derived for determining the optimum weight distribution for two-stage tandem rockets for the case of different structural factors and propellant specific impulses in each stage. Minimization of gross weight for a given required burnout velocity and payload is the criterion of optimization used. For illustrative purposes an example is included in which the optimum distribution is found for a hypothetical chemically boosted atomic rocket.

Introduction

IN DESIGNING multistage rockets, it is desirable to apportion the weight of structure, propellant, etc., among the various stages in such a manner so as to obtain a minimum gross weight for a given performance. This problem was treated by Malina and Summerfield (1)² for the case of a rocket vehicle with an arbitrary number of stages assuming equal structural factors for all stages. Their criterion of performance was the burnout velocity of the last stage, which was to be maximized for a given gross take-off weight. They also assumed the propellant specific impulse to be the same for all stages. Their calculations showed that the value of ν , the ratio of propellant weight to gross weight, should be the same for each stage.

The purpose of the present analysis is to discover the optimum distribution of weight for a two-stage tandem rocket for the case of different structural factors and propellant specific impulses in each stage. The criterion of optimization used—the minimization of gross weight for a given required burnout velocity—is equivalent to that used by Malina and Summerfield. Because of the simplifying assumptions used in this analysis, the answers obtained usually will not correspond exactly to those resulting from a careful design study, but they should constitute a useful starting point in the trial and error procedure needed in a more detailed optimum design effort.

Analysis

The burnout velocity is given by Equation [1], which may be recognized as the classic relationship for flight in a gravitational, drag-free environment. The exhaust velocities are assumed to be constant during burning.

$$V = C_1 \ln \frac{M_{g1}}{M_{o1}} + C_2 \ln \frac{M_{g2}}{M_{o2}} \dots [1]$$

Burnout velocity is V ; C is propellant exhaust velocity; M_g is gross weight; and M_o is burnout weight. The subscripts 1 and 2 correspond to the first and second stages, respectively. The gross weight of the first stage includes the gross weight of the second stage as its payload.

It will be assumed that the structural weight of a stage is proportional to the propellant weight, and that powerplant weight is proportional to stage gross weight.³ While these

assumptions are not unreasonable for large rockets, the constants of proportionality must be carefully chosen for the particular propellant system being considered. Thus

powerplant weight

$$1st\ stage = K_1 M_{o1}; \quad 2nd\ stage = K_2 M_{o2}$$

structural weight

$$1st\ stage = f_1 M_{p1}; \quad 2nd\ stage = f_2 M_{p2} \dots [2]$$

where M_p is propellant weight. These assumptions lead to the typical relations

$$\begin{aligned} M_{o1} &= M_{g2} + f_1 M_{p1} + K_1 M_{o1} \\ M_{o2} &= \bar{M} + f_2 M_{p2} + K_2 M_{o2} \\ M_{p1} &= M_{o1} + M_{p1} \\ M_{p2} &= M_{o2} + M_{p2} \end{aligned} \dots [3]$$

where \bar{M} is the useful payload of the second stage. As it will be convenient to express the performance relation, Equation [1], in terms of M_{o1} and M_{o2} alone, the following expressions are obtained from Equation [3]

$$\begin{aligned} M_{o1} &= \frac{1}{1 + f_1} [M_{o2} + (k_1 + f_1)M_{o1}] \\ M_{o2} &= \frac{1}{1 + f_2} [\bar{M} + (k_2 + f_2)M_{o2}] \end{aligned} \dots [4]$$

Using Equations [4], the performance equation may now be expressed as

$$\begin{aligned} V &= C_1 \ln M_{o1} - C_1 \ln \frac{1}{1 + f_1} [M_{o2} + (k_1 + f_1)M_{o1}] + \\ &C_2 \ln M_{o2} - C_2 \ln \frac{1}{1 + f_2} [\bar{M} + (k_2 + f_2)M_{o2}] \dots [1a] \end{aligned}$$

Now, treating M_{o1} and M_{o2} as variables, and V as a parameter, this equation may be differentiated and the following expression obtained

$$\begin{aligned} \left[\frac{C_1}{M_{o1}} - \frac{C_1(k_1 + f_1)}{M_{o2} + (k_1 + f_1)M_{o1}} \right]_A dM_{o1} + \\ \left[\frac{C_2}{M_{o2}} - \frac{C_2}{M_{o2} + (k_2 + f_2)M_{o2}} - \frac{C_2(k_2 + f_2)}{\bar{M} + (k_2 + f_2)M_{o2}} \right]_B dM_{o2} = 0 \end{aligned} \dots [5]$$

$$\text{Therefore} \quad \frac{dM_{o1}}{dM_{o2}} = - \left[\frac{]_B}{]_A} \right] \dots [6]$$

The criterion for the optimum, or minimum gross weight, is found by setting this differential quotient equal to zero. This is simply the point at which the expression in brackets denoted by B is equal to zero, provided that the expression in the denominator is not also zero. Algebraic manipulation shows that the zero of $[]_B$ is found when

$$\frac{M_{g2}}{\bar{M}} = \frac{1}{C_1(k_2 + f_2)} \left[(C_2 - C_1) + \frac{M_{o1}}{M_{o2}} C_2(f_1 + k_1) \right] \dots [7]$$

It is easily shown that $[]_A$ is never zero (for nonzero M_{o2}); hence the relation given in Equation [7] is the desired optimum criterion.

Now, Equation [1a] may be rewritten using Equation [7]

$$\begin{aligned} V &= -C_1 \ln \frac{1}{1 + f_1} \left[\frac{M_{g2}}{M_{o1}} + (k_1 + f_1) \right] - \\ &C_2 \ln \frac{1}{1 + f_2} \left[\frac{C_1(k_2 + f_2)}{(C_2 - C_1) + \frac{M_{o1}}{M_{o2}} C_2(f_1 + k_1)} + (k_2 + f_2) \right] \end{aligned} \dots [8]$$

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² Numbers in parentheses indicate References at end of paper.

³ The first assumption has been commonly used in simple design studies. The second is based on the consideration that thrust required is proportional to gross weight, and that engine weight is proportional to thrust.

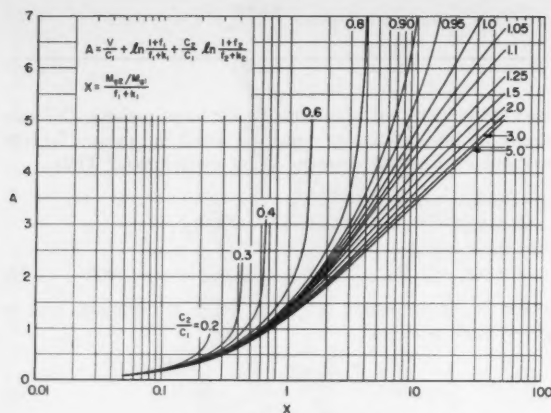


Fig. 1 Plot of Equation [8a]

Because C_1 and C_2 are different, the solution of this equation must be found numerically.⁴ A graph has been prepared to permit the solution of [8] without recourse to trial-and-error methods. In Fig. 1, a parameter (denoted by A) consisting of a collection of terms involving only the given numbers of the problem is plotted against an expression (denoted by X) involving given numbers and the ratio M_{g1}/M_{g2} , which is to be determined. A family of such curves is plotted for various values of the ratio C_2/C_1 . The coordinates of these curves are

$$A = -\frac{V}{C_1} + \ln \frac{1+f_1}{f_1+k_1} + \frac{C_2}{C_1} \ln \frac{1+f_2}{f_2+k_2}$$

$$X = \frac{M_{g1}/M_{g2}}{f_1+k_1}$$

and the equation plotted is obtained by rearrangement of Equation [8].

$$A = \left(1 + \frac{C_2}{C_1}\right) \ln(1+X) - \frac{C_2}{C_1} \ln \left[1 + \left(1 - \frac{C_1}{C_2}\right) X\right] \quad [8a]$$

Then the number obtained for M_{g1}/M_{g2} in [7] is used to obtain M_{g1}/\bar{M} . Now all pertinent weights may be obtained from Equations [2 and 3], using the desired value for \bar{M} .

For the case in which it is expected that the structural and engine weight factors and the effective exhaust velocities are not widely different, the Malina-Summerfield optimum criterion would be adequate as a first cut for a design study. Their criterion may be obtained from [7] by setting $C_1 = C_2$, $k_1 = k_2 = 0$, and $f_1 = f_2$, with the result that $M_{g1}/\bar{M} = M_{g1}/M_{g2}$ for optimum performance. However, for widely differing values of these parameters, the optimum condition according to the present calculation is far different, as will be shown in the following numerical example.

Let us use Equations [7 and 8] to obtain the optimum weight distribution for a two-stage vehicle that is to have a burnout velocity of 25,000 fps. Assume that the first-stage rocket uses chemical propellants, but that the second stage uses an atomic rocket. The various parameters of the problem have been chosen arbitrarily for illustration.

$$\begin{array}{lll} C_1 = 10,000 \text{ fps} & f_1 = 0.15 & k_1 = 0.05 \\ C_2 = 25,000 \text{ fps} & f_2 = 0.25 & k_2 = 0.15 \end{array}$$

Solving Equation [8] through use of Fig. 1 yields $M_{g1}/M_{g2} = 1.97$, and substituting this figure into Equation [7] yields $M_{g1}/\bar{M} = 6.19$. Therefore this configuration requires $6.19 \times 1.97 = 12.19$ lb of take-off gross weight for every pound of

payload accelerated to burnout velocity. One could now proceed with a design study, using the above results and the other weight relations (engines, structure) derivable from them as a good starting point, provided that the parameters of the problem had been well chosen in the first place. It may be instructive to contrast the results obtained above with the results obtained if one simply uses the Malina-Summerfield criterion of equal payload ratios, rather than the optimum criterion of [7], to calculate a design starting point for the chemical atomic two-stage rocket problem. Then, solution of [1a] yields the results that $M_{g1}/M_{g2} = M_{g1}/\bar{M} = 3.79$, and 14.4 lb of take-off gross weight $((3.79)^2)$ are required for each pound of payload. The advantage of the present calculation in giving reduced gross weight through use of the optimizing procedure is apparent.

References

- 1 Malina, F. J., and Summerfield, M., "The Problem of Escape from the Earth by Rocket," *Journal of the Aeronautical Sciences*, vol. 14, Aug. 1947, p. 471.
- 2 Vertregt, M., "A Method for Calculating the Mass Ratios of Step Rockets," *Journal of the British Interplanetary Society*, vol. 15, March-April 1956, p. 95.

Times Required for Continuous Thrust Earth-Moon Trips

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A BRIEF investigation has been made of the times required for rocket flight to the moon assuming continuous thrust along a radius vector. The development of high efficiency nuclear propulsion systems will make such flights possible in the future and will greatly enhance military or scientific interplanetary expeditions.²

In exploring the advantages of nuclear-powered space ships with continuous thrust, compared to chemical impulse-thrust systems, time of flight was selected as an important factor which to date has received too little attention.

The flights studied consisted of three constant-thrust phases; namely, a high-acceleration "boost" phase, a 1 g thrust-acceleration sustainer phase and a 1 g deceleration phase. The objective of the study was to find a simple mathematical expression for the time of flight of a continuous thrust, constant mass rocket travelling radially from the earth to the moon at 1 g constant thrust-acceleration for most of the trip.

During the 1 g thrust-acceleration sustainer phase, the net acceleration of the ship is given by

$$\ddot{r} = g - g \left(\frac{r_0}{r}\right)^2 \quad [1]$$

which can be integrated by setting \dot{r} equal to $r(dr/dr)$ and

$$r d\dot{r} = g \left[1 - \left(\frac{r_0}{r}\right)^2\right] dr \quad [2]$$

This gives

$$\frac{\dot{r}^2}{2} - \frac{v_0^2}{2} = g \left[r - sr_0 + \frac{r_0^2}{r} - \frac{r_0}{s}\right] \quad [3]$$

Where

$$\begin{array}{l} r_0 = \text{radius of the earth} \approx 4000 \text{ miles} \\ v_0 = \text{velocity at the beginning of the 1 g phase} \end{array}$$

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² "The Earth-Moon Constant-Thrust Propulsion," by D. M. Cole, *Jet Propulsion*, vol. 27, Feb. 1957, pp. 178-179.

⁴ An analysis similar to the present calculation has been published recently by Vertregt (2). It shows how an explicit solution may be obtained for the case of equal exhaust velocities.

s = distance in earth radii at the beginning of the 1 g phase
 r = distance measured from center of earth
 g = sea level acceleration of gravity

This expression is difficult to integrate for arbitrarily selected values of v_0 and s . However, a restriction can be placed on the values of v_0 and s which greatly simplifies the problem. First let $v_0^2/2gr_0 = Z$ (where $2gr_0$ is equal to the square of the sea level escape velocity). Now substitute $2gr_0Z$ for v_0^2 in [3] to give

$$\dot{r}^2 = 2g \left[r - \frac{(s^2 - sZ + 1)}{s} r_0 + \frac{r_0^2}{r} \right] \dots \dots [4]$$

If $(s^2 - sZ + 1)/s$ is made equal to -2 by a proper choice of s and Z , then [4] becomes

$$\dot{r}^2 = 2g \left[r + 2r_0 + \frac{r_0^2}{r} \right] = \frac{2g}{r} [r^2 + 2rr_0 + r_0^2] \dots \dots [5]$$

and

$$\dot{r} = \sqrt{2g/r} (r + r_0) \dots \dots [6]$$

or

$$\frac{\sqrt{r}}{r + r_0} dr = \sqrt{2g} dt \dots \dots [7]$$

Thus by selecting values of s and Z an expression is obtained which can be integrated to give

$$\sqrt{2g} t = 2 \sqrt{r} - 2 \sqrt{sr_0} - 2 \sqrt{r_0} \tan^{-1} \frac{\sqrt{r}}{\sqrt{r_0}} + 2 \sqrt{r_0} \tan^{-1} \sqrt{s} \dots [8]$$

This permits calculation of the time for the sustainer or Phase 2 portion of the trip. Phase 2 of the flight was assumed to continue out to $r = 30r_0$ or a little less than half of the distance from the earth to the moon. When this value is substituted in [8] the expression becomes

$$\sqrt{2g/r_0} t = 2 \sqrt{30} - 2 \sqrt{s} - 2 \tan^{-1} \sqrt{30} + 2 \tan^{-1} \sqrt{s} \dots [9]$$

$$t = 19.1 [4.09 - \sqrt{s} + \tan^{-1} \sqrt{s}] \text{ min} \dots \dots [10]$$

Consider an example wherein $s = 4$. The time required for Phase 2 will then be 61 min. The velocity at the end of Phase 2, as given in [6], becomes

$$\dot{r} = \sqrt{2g/30r_0} (31r_0) = 1.42 \times 10^4 \text{ mph}$$

During Phase 3 the ship must be decelerated from 1.42×10^4 mph to zero at a constant rate of $1 g$. Neglecting the gravity of the moon, this process will take 108 min (128,000 miles).

The problem remains to select values of s and Z such that $(s^2 - sZ + 1)/s = -2$ and to determine the accelerations and times for the boost phase. Note that if $s = 1$, then $Z = 4$. Since $v_0^2 = Zv_{\text{escape}}^2$, v_0 must equal twice the sea level velocity of escape. Unfortunately, an infinite boost acceleration would be required, since this velocity must be reached after travelling zero distance. However, if such a velocity were assumed for take-off, and zero time for Phase 1, the total time for the moon trip would be 3 hr 2 min (substitute $s = 1$ in Equation [10] and add 108 min for Phase 3).

If $s = 1.25$ then the thrust acceleration during boost is $17 g$, the time for Phase 1 is 2.3 min, the time for Phase 2 is 73 min and the total time is 3 hr 3 min. If $s = 5$, then the boost acceleration required is $2 g$; the time for Phase 1 is 30 min; for Phase 2, 57 min; and for the total trip, 3 hr 15 min. The relation between boost time, boost acceleration and total trip time is illustrated in Fig. 1. The time for the boost phase

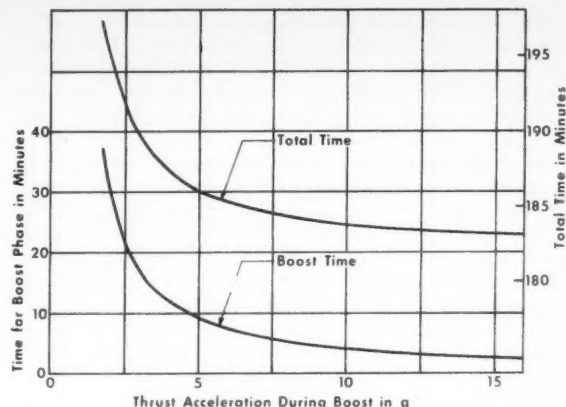


Fig. 1 Times for earth-moon trip for various boost accelerations

can be calculated by using an average value for net acceleration, with little loss in accuracy where boost acceleration ≥ 2 . Fig. 1 shows that for the special case considered, very little is gained by using high boost accelerations. Of the values used, the smallest one ($2 g$) would probably be the most practical. Higher values would require special techniques (such as submerging the crew in water), and stronger structural supports.

It should be noted that since the velocity attained and distance covered at turn around (end of phase 2) is the same for all cases, the energy expended is also the same. For a space ship weighing 100 tons, the total energy required for a trip to the moon in the times presented in Fig. 1, would be 27.9×10^{13} ft lb. If a perfectly efficient fusion reactor were used to provide propulsion energy, 8.6 lb of deuterium would be required for the trip.

The first trips to the moon will probably be made by multi-stage chemical rockets since this art is already well advanced. A trip by chemical rocket, leaving earth or a close satellite orbit at the velocity of escape, would require approximately 49 hr. If the minimum possible impulsive take-off velocity is used (98 per cent of escape velocity), approximately 100 hr would be required for the trip.

Since round trips of four to ten days minimum would require large amounts of provisions and may involve some danger from meteorites and cosmic rays, the advantages of an efficient nuclear rocket are obvious. The possibility of three-hour trips to the moon lends greater significance to such concepts as lunar military bases, scientific laboratories and even tourist travel.

Spin-Stabilized Unsymmetrical Bodies

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The relations that must be satisfied in order to spin-stabilize an unsymmetrical body entering the earth's atmosphere are discussed. It is also pointed out how, in most cases, the Jacobian elliptic functions that satisfy the classical Eulerian dynamical equations can be replaced by the ordinary trigonometric functions.

WHEN a body that is ultimately going to be aerodynamically stabilized is entering the earth's atmosphere, it is imperative to restrict the initial orientation within certain prescribed limits. The simplest method of providing a suitable alignment along the trajectory, when aerodynamic forces are still absent, is to utilize the gyroscopic effect created by an

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initial spin about the axis of minimum (or maximum) inertia. However, there are certain serious limitations to the magnitude of the disturbance that can be handled by some bodies. Relations will be presented to determine the maximum disturbance in angular velocity that can be successfully spin-stabilized by any arbitrary rigid bodies moving in a vacuum.

At re-entry into the earth's atmosphere the aerodynamic forces are at first negligible so the center of gravity follows the same trajectory as a point particle acted upon only by the earth's gravitational field. The rotational motion about the center of gravity is the same as that about a fixed point in space and is most easily described by utilizing the three Eulerian angular velocity components p, q, r about the three principal axes of inertia having the corresponding moments of inertia A, B, C . Since the products of inertia are all zero, Euler's dynamical equations (1, 2 or 3)² reduce to

$$A \frac{dp}{dt} - (B - C)qr = 0 \quad [1]$$

$$B \frac{dq}{dt} - (C - A)rp = 0 \quad [2]$$

$$C \frac{dr}{dt} - (A - B)pq = 0 \quad [3]$$

As is well known, a sufficiently large initial rolling velocity about the axis of symmetry of a body of revolution will produce a periodic Eulerian nutation of the axis of symmetry. This will prevent a continual increase in the angle of deviation of the two remaining axes, and in addition, an increase in rolling velocity can limit the magnitude of the periodic angular deviation to any desired value. For example, if $A < B = C$, then the solutions of Equations [1, 2, 3] give the Eulerian angular velocity components

$$p = p_0 = \text{const.} \quad [4]$$

$$q = r_0 \sin \left[p_0 \left(1 - \frac{A}{B} \right) t \right] \quad [5]$$

$$r = r_0 \cos \left[p_0 \left(1 - \frac{A}{B} \right) t \right] \quad [6]$$

for the case where a disturbance in yawing³ velocity r_0 occurs for a body of revolution that has an initial rolling velocity p_0 about its axis of symmetry. It is seen that as the rolling velocity is increased the magnitude of the periodic variation in yaw angle decreases, the magnitude of the angular deviation in yaw (or pitch) being given in the limiting case by

$$r_0/p_0 \left(1 - \frac{A}{B} \right) \quad [7]$$

However if $B \neq C$, this solution does not apply and there is a definite limit to the disturbing angular velocity that can be accommodated before the actual rotation transfers from the minimum axis of inertia to the maximum axis of inertia, or vice versa. For example, if we take the usual case wherein $A < B < C$, the solutions of Equations [1, 2, 3] for the initial conditions

$$p(0) = p_0, \quad q(0) = 0, \quad r(0) = r_0 \quad [8]$$

are (see (2 or 3))

$$p = p_0 \text{dn}(Nt, k) \quad [9]$$

$$q = r_0 \sqrt{\frac{C(C-A)}{B(B-A)}} \text{sn}(Nt, k) \quad [10]$$

$$r = r_0 \text{cn}(Nt, k) \quad [11]$$

² Numbers in parentheses indicate References at end of paper.

³ The definitions of rolling (p), pitching (q) and yawing (r) velocities are the usual aircraft or missile notation as given in (1) when the axis of least inertia A is primarily in the direction of the trajectory.

where

$$N = p_0 \sqrt{\left(1 - \frac{A}{B} \right) \left(1 - \frac{A}{C} \right)} \quad [12]$$

and

$$k = \frac{r_0}{p_0} \sqrt{\frac{C}{A} \left(\frac{C-B}{B-A} \right)} < 1 \quad [13]$$

The Jacobian elliptic functions, dn , sn and cn are simply periodic (as in Fig. 1) as long as k is a real number and $0 \leq k < 1$; that is, as long as $A < B < C$ and r_0 is sufficiently small. Actually for $k < 1/2$ (see Fig. 1 and (3)), the elliptic functions have

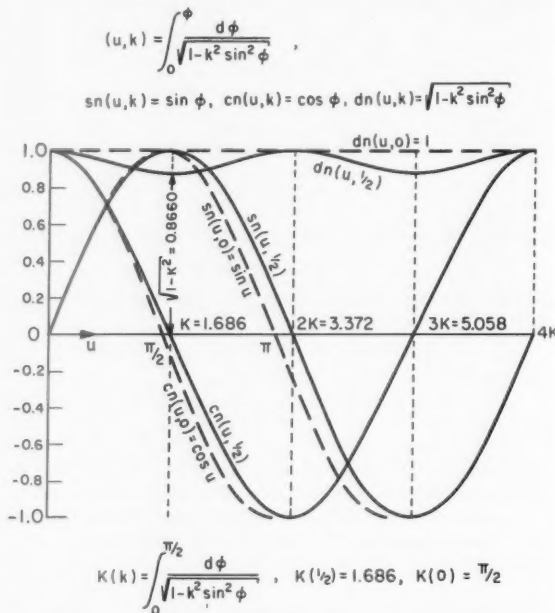


Fig. 1 Elliptic functions (u, k) for $k = 1/2$ and $k = 0$

a periodic behavior that is within 7 per cent of that of the corresponding trigonometric functions to which they exactly reduce when $k=0$. Therefore if $0 \leq k < 1$, Equations [9, 10, 11] behave similarly to Equations [4, 5, 6], the principal difference being that the magnitude of q will now be greater than the original r_0 disturbance. The equations are of course identical when $k=0$; that is, for $B = C$.

However, when $k > 1$ these solutions are no longer valid. In this case k is defined by the reciprocal of Equation [13] and the continual rotation transfers to the yawing velocity ($r \sim r_0 \text{dn}$) while the rolling velocity becomes periodic ($p \sim p_0 \text{cn}$). The pitching velocity ($q \sim \text{sn}$) remains periodic about the intermediate moment of inertia axis for all cases except the extremely unstable situation that arises when k is exactly unity so the solutions reduce to (see (2 or 3))

$$p = p_0 \text{sech } Nt \rightarrow 0 \quad [14]$$

$$q = p_0 \sqrt{\frac{A}{B} \left(\frac{C-A}{C-B} \right)} \tanh Nt \rightarrow \text{const.} \quad [15]$$

$$r = p_0 \sqrt{\frac{A}{C} \left(\frac{B-A}{C-B} \right)} \text{sech } Nt \rightarrow 0 \quad [16]$$

The instability of this solution for rotation about the intermediate moment of inertia axis was first proved geometrically by Poincaré (2). It can also be demonstrated by noting that the slightest finite decrease of k from unity makes the Jacobian elliptic functions periodic, and thus behave like the trigono-

metric functions rather than the hyperbolic functions. As an illustration, when k is reduced from unity to 0.9999 the period (4K, see Fig. 1) is decreased from infinity to 7π , whereas the further reduction of k to zero only decreases the period to 2π .

A deleterious effect occurs when manufacturing irregularities or a misalignment of the applied rolling torque create products of inertia; that is, whenever the initial spin is not exactly about a minimum (or a maximum) moment of inertia axis. Euler's dynamical equations (1 or 2) show that finite products of inertia will distribute some of the applied angular momentum to each of the axes. The transfer of angular velocities becomes undesirably large whenever the moments of inertia have nearly the same magnitude. Of course when $A = B = C$, the products of inertia vanish for any choice of axes, since each and every axis is a principal axis. However Equations [1, 2, 3] show that then the rotation about any axis is stable and completely independent of the rotation about any other axis. Consequently an initial spin cannot prevent a continual rotation about any other slightly disturbed axis whenever the moments of inertia have exactly the same magnitude.

Conclusions

An arbitrary rigid body with three unequal moments of inertia, $A < B < C$, can be spin-stabilized by rolling (p) about the minimum moment of inertia (A) axis only as long as

$$k = \left[\frac{\frac{C}{B} \left(\frac{C-A}{B-A} \right) r^2 + q^2}{\frac{A}{B} \left(\frac{C-A}{C-B} \right) p^2 + q^2} \right]^{1/2} < 1$$

In the event that $k < 1/2$, the Jacobian elliptic functions dn , sn , cn can be replaced by the corresponding trigonometric functions 1 , \sin , \cos with a periodic error less than 7 per cent.

For spin-stabilization by yawing (r) about the maximum moment of inertia (C) axis, the above considerations are still applicable provided k is defined by the reciprocal of the above relation.

References

- 1 Jones, B. Melville, "Dynamics of the Aeroplane," vol. V of "Aerodynamic Theory, Div. N," W. F. Durand, edit., Springer, Berlin, 1934, pp. 122-124.
- 2 Synge, J. L., and Griffith, B. A., "Principles of Mechanics," McGraw-Hill, New York, 2nd edit., 1949, pp. 331, 351-356, 364, 419.
- 3 Milne-Thomson, L. M., "Jacobian Elliptic Function Tables," Dover, New York, 1950, pp. 2, 22, 41, 63, 85.

Vapor Pressure and Heat Contents of Saturated Liquid and Vapor Hydrogen Peroxide

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This paper presents a new vapor pressure equation and graph for anhydrous hydrogen peroxide and also tables and a graph representing the heat contents of pure saturated liquid and vapor hydrogen peroxide. The calculation techniques are somewhat novel and provide an excellent representation of the data together with thermodynamic consistency between the vapor pressures and heats of vaporization.

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³ Proper units are shown in body of text.

⁴ Numbers in parentheses indicate References at end of paper.

Nomenclature³

A, B, C	= constants in the vapor pressure equation
C_p°	= specific heat of the gas at zero pressure (or the standard state)
H°	= heat content of the gas at zero pressure (or the standard state)
H_0°	= heat content of the gas at zero pressure (or the standard state) at 0 K
H_{sat}	= heat content of saturated vapor
h_{sat}	= heat content of saturated liquid
ΔH_V	= heat of vaporization
P	= vapor pressure
R	= gas constant
T	= temperature
Z	= gas or liquid compressibility factor in the equation $PV = ZRT$
ΔZ	= difference between gas and liquid compressibility factors

RAPIDLY broadening uses for hydrogen peroxide, both in military and civilian uses (1),⁴ have focused attention on the physical properties of this compound in the pure state. In this article we will present an equation and a graph for the vapor pressure and also a tabulation and graph of the heat contents of the liquid and vapor, both in the saturated state. The calculation methods described were deemed to give accurate and thermodynamically sound representations of the desired physical properties.

The vapor pressure of hydrogen peroxide was derived from the heat of vaporization by means of the Clapeyron equation. The heat of vaporization was measured calorimetrically at 0 C (12,591.7 \pm 6 cal/mole) by Foley and Giguère (2) and at 25 C by Giguère et al. (3) (12,330 cal/mole). At low vapor pressures (5 to 7 mm), $\Delta Z_{H_2O} = 1 - 0.001 P_{mm}$, where ΔZ is the difference in compressibility factor Z between vapor and liquid assuming that both gas and liquid P - V - T properties can be described by

$$PV = ZRT \dots \dots \dots [1]$$

Assuming that $\Delta Z_{H_2O_2} = \Delta Z_{H_2O}$ at the same pressure and accepting the hydrogen peroxide vapor pressure measurements of Scatchard et al. (7) to estimate $\Delta Z_{H_2O_2}$, we now have ΔH_V and ΔZ at two temperatures, as follows

t , °C	P , mm	ΔZ	ΔH_V , cal/mole	$\Delta H/\Delta Z$, cal/mole
0	0.271	0.999973	12,591.7	12,592
25	2.0	0.999800	12,330	12,332

If we assume that

$$\frac{\Delta H_V}{\Delta Z} = A + BT \dots \dots \dots [2]$$

we can evaluate A and B , obtaining the equation

$$\frac{\Delta H_V}{\Delta Z} = 15,433 - 10.40T \dots \dots \dots [3]$$

where T is the temperature in °K, and ΔH_V is in cal/mole. From the Clapeyron equation, we obtain

$$\frac{d \ln P}{d(1/T)} = \frac{\Delta H_V}{\Delta Z R} - \frac{A + BT}{R} \dots \dots \dots [4]$$

Integrating Equation [4] results in

$$\log P = \frac{A}{2.303RT} + \frac{B \log T}{R} + C \dots \dots \dots [5]$$

The constant term C was evaluated by combining the vapor pressure data of Scatchard et al. (7) with that of Maas and Hiebert (5) to give the final equations

$$\log P_{mm} = 24.594655 - \frac{3375.1}{T} - 5.23700 \log T, T \text{ in } ^\circ K. \dots [6]$$

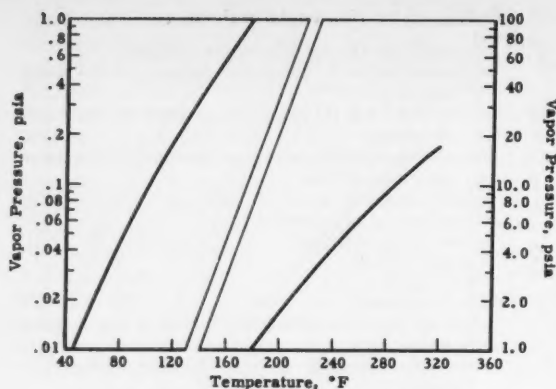


Fig. 1 Vapor pressure of hydrogen peroxide⁵

or

$$\log P_{\text{psia}} = 24.217716 - \frac{6075.2}{T} - 5.23700 \log T, T \text{ in } ^\circ\text{R.} \quad [7]$$

The vapor pressure equations are shown graphically in Fig. 1. The comparison between the calculated vapor pressures and the experimental data was within the error of the experimental data. The advantage of the method used here in deriving a vapor pressure equation by using the heats of vaporization directly over correlating vapor pressure data alone is that thermodynamic consistency is achieved in the process; in addition, with a polar substance such as hydrogen peroxide, it is felt that the deviations from ideality of the vapor should also be taken into account. A comparison of some experimental vapor pressure data (7, 8) with those of Equation [6] and the equation of Scatchard et al. (7) is shown in Table 1.

Table 1 Vapor pressures of hydrogen peroxide (mm Hg)

Temp., °C	From Eq. [6]	From Eq. of (7, 8)	Experi- mental data of (7, 8)
60	17.90	17.53	17.7
90	78.29	78.23	78.4

Latent heats of vaporization were calculated from Equation [6] with the assumption that $\Delta Z_{\text{H}_2\text{O}_2} = \Delta Z_{\text{H}_2\text{O}}$ at the same pressure. The $\Delta Z_{\text{H}_2\text{O}}$ values were taken from the data of Osborne et al. (6). It was assumed that $(H^\circ - H_{\text{sat}})_{\text{H}_2\text{O}_2} = (H^\circ - H_{\text{sat}})_{\text{H}_2\text{O}}$ at the same pressure, where the $(H^\circ - H_{\text{sat}})_{\text{H}_2\text{O}}$ values were obtained from Keenan and Keyes (4). Values of C_p° and $H^\circ - H_0^\circ$ were taken from Giguère et al.

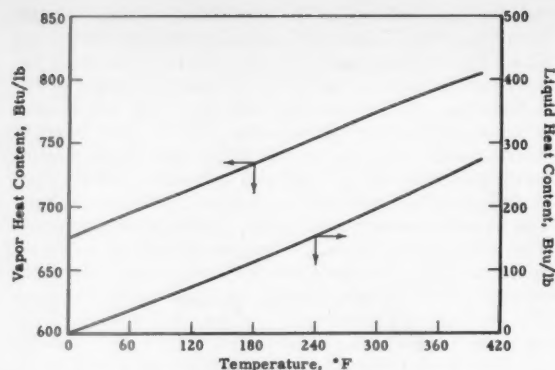


Fig. 2 Heat content of hydrogen peroxide⁶

(3). The value of H° at 0 F was set at 22,999 Btu/mole from the value of ΔH_V to give $h_{\text{sat}} = 0$ at 0 F. Then H° at 40 F intervals was calculated using average values of C_p° for each interval. The values of $(H^\circ - H_{\text{sat}})$ were subtracted from H° to yield values of H_{sat} . Thus knowing ΔH_V and H_{sat} the heat content tables were constructed as shown in Table 2 and Fig. 2.

The liquid heat capacities calculated from the slope of the saturated liquid heat content curve of Fig. 2 show excellent agreement with the experimentally measured values of Giguère et al. (3) and Foley and Giguère (2).

References

- 1 Anonymous, "Rocketing Peroxide Output," *Chemical Week*, March 3, 1956, p. 72.
- 2 Foley, W. T., and Giguère, P. A., "Hydrogen Peroxide and Its Analogues," *Canadian Journal of Chemistry*, vol. 29, 1951, p. 895.
- 3 Giguère, P. A., Liu, I. D., Dugdale, J. S., and Morrison, J. A., "Hydrogen Peroxide: The Low Temperature Heat Capacity of the Solid and the Third Law Entropy," *Canadian Journal of Chemistry*, vol. 32, 1954, p. 117.
- 4 Keenan, J. H., and Keyes, F. G., "Thermodynamic Properties of Steam," John Wiley and Sons, New York, 1946.
- 5 Maas, O., and Hiebert, P. G., "The Properties of Pure Hydrogen Peroxide. V. Vapor Pressure," *Journal of the American Chemical Society*, vol. 46, 1924, p. 2693.
- 6 Osborne, N. S., Stimson, H. F., and Ginnings, D. C., "Measurements of Heat Capacity and Heat of Vaporization of Water in the Range 0° to 100°C," *Journal Research National Bureau of Standards*, vol. 23, 1939, p. 261.
- 7 Scatchard, C. S., Kavanagh, G. M., and Ticknor, L. B., "Vapor Liquid Equilibrium. VIII. Hydrogen Peroxide-Water Mixtures," *Journal of the American Chemical Society*, vol. 74, 1952, p. 3715.
- 8 Schumb, W. C., Satterfield, C. N., Wentworth, R. L., "Hydrogen Peroxide," Reinhold, New York, 1955.

⁵ Source: References (2, 3, 5, 7).

⁶ Source: References (3, 5, 7).

Table 2 Heat content of hydrogen peroxide saturated vapor and liquid

Temp., °F	ΔZ , H ₂ O	ΔH_V , Btu/mole	H_{sat} , Btu/lb	h_{sat} , Btu/lb
0	0.999994	22,999	676.12	0
40	0.999956	22,582	688.70	24.84
80	0.999768	22,162	701.49	49.98
120	0.999284	21,735	714.55	75.58
160	0.99830	21,299	727.54	101.39
200	0.99620	20,840	740.71	128.06
240	0.99284	20,356	753.88	155.46
280	0.98797	19,845	767.02	183.62
320	0.98123	19,302	779.96	212.52
360	0.97183	18,713	792.54	242.52
400	0.95782	18,044	804.56	274.11

Comments on 'Dynamics of a Liquid Rocket System'¹

JOHN C. SANDERS²

NACA, Lewis Flight Propulsion Laboratory,
Cleveland, Ohio

AN IMPORTANT feature of "Dynamics of a Liquid Rocket System"¹ is the listing of the assumptions that can be a guide to other workers in the field. This importance arises from the fact that the authors work with a company engaged in experimental programs. These programs provide guides to the significant features that must be represented and those features that may be overlooked, thus greatly reducing the work. The assumptions seem to agree with those used by other companies doing experimental work on rocket controls.

The paper lost some of its value when the time scales were divided by an arbitrary unknown number to conceal classified information. This procedure would not have caused a loss if all of the dynamic terms had been reported. The missing dynamic terms are

$$\frac{L^* K_{13}}{C^*} = \tau_c = \text{thrust chamber "stay time"}$$

$$\frac{K_{14} \rho_{oz}}{2R_{oz} \bar{Q}_{oz}} = \tau_{oz} = \text{oxidizer line time constant}$$

$$\frac{K_{14} \rho_f}{2R_f \bar{Q}_f} = \tau_f = \text{fuel line time constant}$$

$$\frac{I}{\frac{\partial U_t}{\partial \delta} - \frac{\partial U_p}{\partial \delta}} = \tau_p = \text{turbine-pump time constant}$$

These time constants are derivable from the nonlinear differential equations given in Table 1 of the paper. For the propellant lines the equation is

$$(P_d - P_c) = RQ^2 + (K_{14}\rho) \dot{Q}$$

This equation may be restated as

$$\frac{(P_d - P_c)}{2RQ} = \frac{Q}{2} + \frac{(K_{14}\rho)}{(2RQ)} \dot{Q}$$

The coefficient for \dot{Q} is equal to the time constant of the linearized form of this equation

$$\tau = \frac{K_{14}\rho}{2RQ}$$

When τ also fits the equation

$$\frac{P_d - P_c}{2R\bar{Q}} = Q(\tau_s + 1)$$

In this equation \bar{Q} is the mean steady value. The advantage of quoting time constants is that they are easily understood, and the relative contributions of time delays in the propellant systems, the combustion lag and the combustion chamber "stay time" can be perceived.

It is hoped that the authors can give these numbers or the nonlinear equivalents even if they are divided by the arbitrary constant τ_b . Otherwise the reader cannot get the faintest understanding of the contribution of the terms considered important by the authors.

This discussion is not a criticism of the paper, but rather a suggestion for a means of protecting classified information

Received Nov. 20, 1956.

¹ By Marvin R. Gore and John J. Carroll, JET PROPULSION, vol. 27, Jan. 1957, pp. 35-43.

² Chief, Controls Branch.

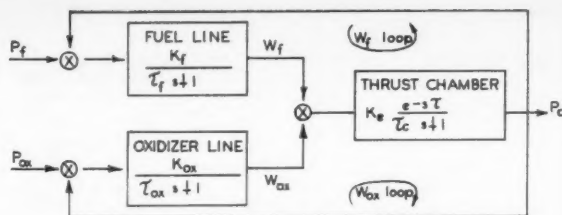


Fig. 1 Loops used in calculating gain

while at the same time presenting enough essential information so that the reader can understand the results.

One minor criticism concerns the use of loop gain. The definition of loop gain K_{OL} given under "Propellant Lines-Thrust Chamber Loop Dynamic Characteristics" differs from the usage of the controls literature, and could not be used in dynamic equations. Actually two parallel loops exist, as shown in Fig. 1.

The individual loop gains are

$$\text{for } W_f: K_L = K_f K_e$$

$$\text{for } W_{ox}: K_L = K_{ox} K_e$$

For the complete "figure 8" or interacting double-loop gain

$$KL = K_f K_{ox} K_e = K_f K_{ox} K_e^2$$

A very useful application of the analog model given in this paper is in a study of the system behavior in the presence of disturbances in combustion pressure P_c resulting from normal combustion noise. Noise applied to the system whose performance is shown in Fig. 7 would make the transient for 25 per cent rated thrust appear as almost continuous oscillation. For this test the low-pass filter will not be very significant and it may become necessary to provide more accurate representations of the dynamics of the propellant lines and pumps.

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Tally Sheet on U. S. Test Tracks

Name	Location	Length (ft)	Test Speeds (mph)	Braking Devices	Test Applications
B-4	U. S. Naval Ordnance Test Station, China Lake, Calif.	14,500	1300	Sand piled between rails	Guided missile components such as fuzes, warheads, guidance and control devices; and aircraft missile launchers
SNORT (Supersonic Naval Ordnance Research Tract)	U. S. Naval Ordnance Test Station, China Lake, Calif.	21,500	2386	Probe and horizontal momentum exchange water brakes	Escape systems, aerodynamic flutter, armament compatibility inertial guidance components, environmental testing
G-4	U. S. Naval Ordnance Test Station, China Lake, Calif.	3,000	1364	—	Warhead and fuze functioning under free flight conditions
—	Air Force Flight Test Center, Edwards, Calif.	2,000	204	Hydro-mechanical brakes	Aircraft seats, inertia reels, crash restraint harnesses, litter restraining devices, and other equipment subject to high rectilinear deceleration forces
FATF (Free Air Test Facility)	Air Force Flight Test Center, Edwards, Calif.	10,000	1364	Water brakes	Seat ejection, parachute programs, tail flutter
Damage Potential Launcher	Air Force Armament Center, Eglin AFB, Fla.	2,000	—	—	Terminal ballistics of air armament, crosswind ballistics of rockets, performance and reliability of retro rockets and their ignition systems
Rocket Launching Track	Air Force Armament Center, Eglin AFB, Fla.	502	—	—	Simulated aircraft launching of rockets
Terminal Ballistic Track	Aberdeen Proving Ground, Aberdeen, Md.	2,448	2676	—	Rocket warhead and fuze functioning; free-flight, induced yaw, fragmentation, penetration, telemetering
SMART (Supersonic Military Air Research Track)	Air Force Test Center, Hurricane Mesa, Utah	12,000	1400	Hydro-mechanical brakes	High speed ejection, bailouts, survival equipment

Test Tracks Bring Flight Problems to Earth

HIGH-SPEED track testing has come a long way in the past decade. Just how far, missile men found out this month in Washington, at the Spring Meeting of the AMERICAN ROCKET SOCIETY.

The Human Element: George Smith, test pilot for North American Aviation, ejected from an F-100A jet fighter over the Pacific on the morning of Feb. 26, 1955. At ejection, the plane was moving at Mach 1.05 in a near vertical dive at an altitude between 5000 and 7000 ft.

Within an hour and a half, Smith was in a hospital (he lived), and one of the most intensive investigations in aviation history was under way on emergency escapes. This, the first known instance of a pilot making a supersonic, low altitude bail-out, boldly underscored the urgent need for additional information in this area.

To answer this need, North American engineers turned to Wright Air Develop-

ment Center's Experimental Track Branch at Edwards Air Force Base. Here, they recreated Smith's bail-out on a highly instrumented high speed test track (see pictures).

Among other results of this study to date, as North American's James F. Hegenwald, Jr., and Edward A. Murphy, Jr., reported, it appears that the combined hazards of acceleration, noise, windblast, and limb flailing in short term exposures such as Smith's are somewhat less perilous than anticipated.

While Hegenwald and Murphy emphasized that further research along these lines is essential, they noted that it is already apparent that results from this study could lead to more efficient aircraft design where "neither the operator nor the vehicle would be encumbered by unessential safety provision."

Also concerned with pilot safety, Convair's Hugo F. Mohrlock, Jr., was interested in test tracks only to the

point where they furthered the development of ejection seats. The four problems associated with escape from high speed aircraft, Mohrlock said, are low level ejection, fin clearance, tumbling and windblast. With the exception of some windblast effects, he believes that a rocket-propelled, upward-ejection seat such as Convair's RESCU Mark I (now undergoing tests at Edwards AFB) would solve the other problems.

The goal that most scientists in this area are aiming for is a workable escape capsule, but they concede this is still some time away. Meanwhile, work on ejection seats is fast moving to a successful conclusion. Lockheed Aircraft, for example, recently took the wraps off its new "flying seat," which features a steel plate on the end of a 4-ft boom for deflecting windblast away from the pilot. Lockheed engineers have been putting the seat through its paces at the Air Force test track on Hurricane Mesa, expect to have it in production this year.

Dummies Have Their Place



IN EMERGENCY ESCAPE TESTS: After being instrumented, NAA dummy is installed in high speed test sled at Edwards AFB.



PREPARING FOR RUN, workers attach rockets to sled, ready headgear for special helmet-testing boom which rides behind dummy.



READY: Prototype helmet is pushed into airstream at Mach .68; at Mach .98, dummy ejects. Results are shown in last two pictures.

Track Trend: Concerning the tracks themselves, panel members noted many instances of progress.

Items:

- Approval has been granted, according to Engineering Section Chief Ross R. Seger, to double the length of the 10,000-ft track at Edwards AFB (see chart). This will push test speed capabilities to over Mach 3, facilitate testing of complete weapons systems. It will also permit greater use, says Seger, of the

more economical liquid propellant rocket engine.

- Pointing up the growing importance of high speed test tracks, B. R. Egbert and D. P. Ankeney of the U. S. Naval Ordnance Test Station at China Lake, Calif., disclosed that approximately 500 test runs were made on the supersonic tracks at NOTS last year, an increase of 63 per cent over the number of runs in 1955.

- Mitchell E. Bonnet, Aberdeen Prov-

ing Ground, reported that over 700 runs had been made on the Aberdeen track since it went into operation in October 1953. The Army is considering lengthening the track to obtain higher velocities.

- Construction of the 2000-ft Damage Potential Launcher at Eglin AFB has been completed. Designed for weapons evaluation, it provides the Air Force Armament Center with its first supersonic test track capability, according to

AFAC's Richard E. Hendricks.

The Redstone Arsenal Ballistic Ramp was covered in a paper by the Arsenal's K. L. Carroll while William T. Bateman and Gerhard R. Eber of Holloman Air Development Center reported on test tracks there. Bateman discussed design determinants for the Holloman horizontal test stand and Eber detailed the capabilities of the Holloman high speed track.

Closed Circuit: More of a proposal than a report, the paper by Chicago Midway Laboratories' H. J. Barten on "The Closed Circuit High-Speed Test Track" kindled the audience's collective imagination.

Barten's thesis: To obtain high velocities on conventional test tracks, the engineer must sacrifice the test vehicle or track length (i.e., part of the track must be reserved for braking). A closed circuit track with circular sections might avoid this problem.

Such a track, he maintained, would make braking unnecessary, since friction due to centrifugal forces would slow down the vehicle after burnout, and would permit recovery of captive test items and test vehicles.

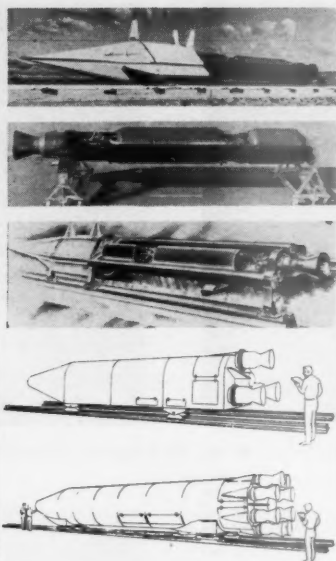
On the other hand, said Barten, there would be disadvantages too. Large danger areas would be required; multiple boost vehicles might need additional rails; and there would be high centrifugal load factors at high speeds.

Powerplants: Along with—and sometimes pushing from behind—these recent advances in high speed track testing, declared H. Davies and D. S. Smith, has been the accelerated development of suitable powerplants.

After noting the advantages of liquid rocket powerplants for this work, Davies and Smith of lpr-pioneering Reaction Motors, Inc., revealed that RMI has a contract to design, develop and deliver two large liquid propellant pusher vehicles to Edwards AFB.

The first will be a transonic vehicle able to attain and sustain (for 2 sec) any selected velocity between 900 fps and 1350 fps while pushing a 5000-lb test

LPR Sleds



Top photo shows typical lpr sled configuration; immediately below are two new lpr units, AJ10-28 and AJ10-36, developed by Aerojet for SNORT. Bottom photos show transonic and supersonic lpr sled under development at RMI for Edwards AFB.

sled. The second will be a supersonic vehicle able to attain and sustain, also for 2 sec, a predetermined velocity between 1100 fps and 2300 fps while pushing a 10,000-lb test sled. Both vehicles will probably be powered by a combination of JP-4 and 90 per cent hydrogen peroxide.

Taking a somewhat similar tack on lpr powerplants, C. E. Roth, Jr., and H. M. Poland of Aerojet-General Corp. reported that the two new lpr sleds (AJ10-28 and AJ10-36) developed by Aerojet for the Navy's SNORT facility had successfully completed 45 static and 16 dynamic tests. This, they concluded, has demonstrated the feasibility of using

liquid propellant rockets for supersonic sleds—an application well established in concept but comparatively new in operation.

Rounding out this report, Eugene C. Graham of the Experimental Track Branch at Edwards AFB described the evolution of a supersonic track propulsion system. Related to this, the design of vehicles for high speed track development programs was discussed by Richard A. Hirsch of Aircraft Armaments, Inc. Richard F. Chandler, Holloman Air Development Center, carried the subject further in his report on mechanical problems of track vehicle design.

Testing: Instrumentation, the heart of most track testing, lacks the preciseness missile scientists feel they need for many projects—e.g., the use of a supersonic sled to test components of all-inertial guidance systems. At the ARS Spring Meeting, panel members suggested some remedies.

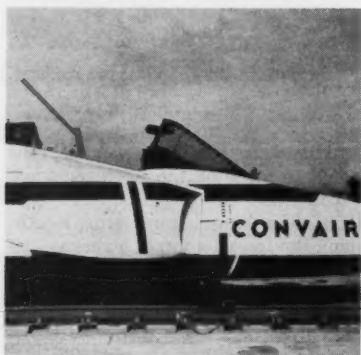
F. J. Beutler of the Ramo-Wooldridge Corp. and L. L. Rauch of the University of Michigan detailed a method of combining track-coil and accelerometer data to provide the necessary precision with computational simplicity.

Electronic Engineering Co. of California has taken a somewhat different approach to the problem, reported EEC's R. I. Anderson. The company has developed a track data system based on the Doppler principle. Tagged Project DATUM, the system is now undergoing tests at Edwards AFB.

The subject of high speed test track instrumentation received over-all treatment from Warren H. Sanders of Holloman Air Development Center, while G. M. Barr and S. C. Morrison of Ramo-Wooldridge Corp. concentrated on measuring the vibration environment in a supersonic lpr sled.

Somewhat less concerned with instrument preciseness, K. Barr of Edwards' Experimental Track Branch and E. J. Steeger of Convair were interested in the test track mostly for its high speed capability. They wanted to check rain-erosion resistance of various radome materials at velocities up to and above Mach 2. In doing this, they also initiated a new high speed track testing technique—rain erosion using a simulated rainfall curtain—and established routine operation of a Mach 2 vehicle.

Second to None: Whatever else may result from these recent advances in high speed track testing (and a great deal is expected), missile men knew they had definitely established the high speed test track as a top research tool. In probing the vast supersonic unknown, asserted Ankeney and Egbert, it has taken its place alongside the wind tunnel, centrifuge, shake table, and engine test stand.



TANDEM TESTING: In developing its emergency escape seat RESCU Mark 1, Convair used tandem sled seating to compare its prototype with other seats.



Chemicals Etch Way Into Missile Industry

THE world's largest Chem-Mill processing facility is now onstream. The new plant is located in Downey, Calif., at North American Aviation's Missile Development Div., where it will serve to shape stainless steel and titanium parts for the company's Navaho missile.

According to Division general manager J. G. Beerer, chemical etching will enable NAA to process large metal parts "to accuracies impossible by conventional milling methods." Chemical milling, said Beerer, gives engineers greater latitude in designing missile and aircraft parts to obtain more strength with less weight.

In the development of the Navaho alone, the process has saved hundreds of pounds of design weight. As a result, it has made possible greater payload and fuel capacities and, subsequently, greater range for the missile.

Moreover, chemical milling is faster than many machine methods. In the time it takes to turn out one piece by conventional skin milling methods, Beerer points out, Chem-Mill can work as many surfaces as the etching tank can hold. And it is estimated that the process costs less than machine milling.

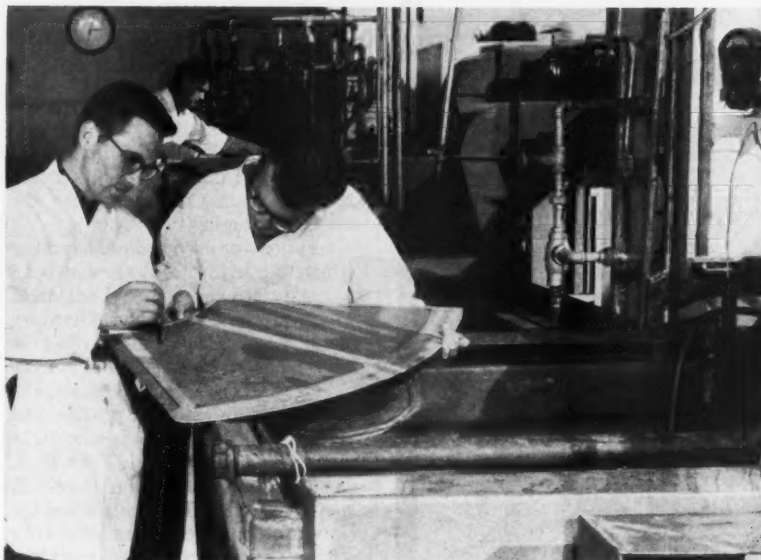
Consumption of chemical etching agents, of course, is a major cost factor in the process. But the savings in time, labor (unskilled hands can do the job), and finishing operations (Chem-Milled surfaces seldom require the usual buffing or polishing) more than offset this. In addition, it does not require as heavy a capital investment.

Beneath the Mask: Chemical milling is essentially the old art of etching updated with many refinements and applied on a large scale. It involves the use of chemicals to mill metals to certain shapes and sizes, together with chemical-resistant masking materials to protect adjacent areas that are to be kept intact.

Basically a simple technique, it has required much research, engineering effort and ingenuity to make it suitable for modern-day mass production operations. Formulation of etching agents, development of masking materials and methods, and application of mass production techniques have all been problems; some still are.

As now set up, this is how chemical milling might work in a typical operation: (1) The incoming part is first degreased, (2) cleaned with hot alkali, (3) rinsed, (4) washed with acid, (5) rinsed and (6) masked.

The mask may be painted, stenciled, drawn or printed on the areas to be protected. Vinyl films, synthetic rubbers,



Supervisor carefully checks progress on metal in Chem-Mill etching tank.

particularly of the neoprene type, and photosensitive gelatines have been suggested as masking materials.

The masked part now goes (7) into the etching tank. After it is etched, it is (8) rinsed, (9) oxides are washed away, (10) masking material is washed off, (11) the part is rinsed and (12) inspected.

Because time, temperature and strength of solutions can be rather precisely controlled, tolerances to 0.002 in. can be achieved with chemical milling. Etching agents, of course, mill not only downward, but also sideways, under the edge of the mask. The degree of this side etching, however, is reported to be controlled easily. And when some areas are to be etched less deeply than others, the part is simply removed from the etching tank, those areas masked, and the part re-immersed.

Developed originally for application to aluminum, the Chem-Mill process holds promise for the milling of most metals. In addition to aluminum, the process has already demonstrated its suitability to titanium, steel and magnesium.

Back Home: It is fitting that this newest and biggest Chem-Mill facility is located at NAA's Downey plant, for it was here that the process was conceived. In 1952, Manual C. Sanz, chief of the materials research section in NAA's Missile Development Div., was working on the development of the Navaho missile.

The problem arose when an aluminum sheet had to be formed into a cylinder of desired curvature. To make sure the

seam would hold after forming, heavy gage aluminum sheets were required. This added what the engineers considered excess weight to the missile. And machining the cylinder down once it was formed proved next to impossible.

It was at this point that Sanz conceived the idea of milling the cylinder down with strong chemicals. North American Aviation applied for a patent (U.S. Pat. 2,739,047, granted in 1956), placed the first Chem-Mill pilot plant in operation in 1953.

Since then, North American has extended process applications to its new jet aircraft and has licensed Chem-Mill through an arrangement with Turco Products, Inc., Los Angeles, to more than 40 other missile, aircraft, and component companies. Some of the licensees are apparently making as extensive use of the process as North American. Convair, for example, is already chemically etching parts for its F-102 and F-106 jet fighters and for its Terrier missile. Moreover, it is likely that when the Tartar missile starts coming off Convair production lines it too will contain chemically milled parts.

Just how far chemical milling will go in missile production is a moot question at this point. No one is betting the chemical process will completely displace conventional machine operations. But at the same time, many engineers, faced with the problem of shaping the tough, high temperature materials of tomorrow's missiles, figure exploitation of chemical milling's potential has just begun.

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Missiles Featured at IRE Show

LONG-range telemetering and remote control, reliability programs, and strides in micro-miniaturization were among the topics pertinent to the missile field that were covered at the national convention of the Institute of Radio Engineers in New York last month.

Close to 50,000 engineers sat in on the 55 technical sessions at the Waldorf-Astoria Hotel and wandered through the two and a half miles of exhibits at the huge New York Coliseum during the three-day gathering.

Reception problems in long-range telemetering have forced engineers to go to bigger and more powerful antennas, according to James B. Wynn of Century Electronic Co. Mr. Wynn described the latest unit, a high gain, automatic tracking parabolic antenna measuring 85 ft in diam in an extended position and weighing 72,000 lb, which is now under construction at Patrick Air Force Base.

At the same symposium, Daniel T. Sigley of Firestone Tire and Rubber Co. pointed out how even the smallest error in space flight calculations is magnified out of all proportion in the end result. An error of 0.47 fps in the velocity of a satellite in an orbit 780 miles from the earth, he said, would cause an altitude change of 1000 ft. An error of 1 fps in a lunar orbit would change the orbit by 750,000 ft, or more than 140 miles, he added.

The Rome Air Development Center, Rome, N. Y., has come up with a reliability program for electronic equipment. Under this program, a "probability of failure" number is assigned to each component, Joseph J. Naresky said, and combinations of these numbers give an over-all reliability value for the assembled equipment. This permits specification of reliability in terms of percentage.

Another paper on the subject, by E. F. Detinger of ARMA Div., American Bosch Arma Corp., described a "long-range" approach to installing high initial reliability in the development and production of inertial guidance systems for the ICBM. Costly though such a reliability system now is, it will pay for itself many times over by saving even one missile from early failure.

Latest orders to miniaturize equipment also include instructions to "make it more reliable," according to Cleo Brunetti of General Mills, Inc. And as the instruments shrink, terminology describing the reduction becomes lengthened—from miniaturization to sub-miniaturization to micro-miniaturization. Dr. Brunetti calls a halt at this point, labeling the last "the ultimate technique" if a particular item cannot be substantially reduced further in size and weight.

Two recent miniaturizations, both made possible by transistors, were announced: A strain gage oscillator by Electronic Engineering Co. and a wide-band transistorized pulse amplifier by Radiation, Inc.

One of the most interesting new wrinkles announced at the show was a relatively efficient nuclear battery. Radioactive wastes such as Strontium-90 will be used to heat (through beta decay) the hot junction of a thermopile to generate up to one watt of power at efficiencies between 3 and 5 per cent, J. L. Briggs of the Rome Air Development Center reported. Present nuclear batteries employing beta decay but through different mechanisms have efficiencies of about 1/2 per cent, while the Russians have reportedly achieved an astounding 13 per cent in work at the University of Leningrad, he noted.

Mr. Briggs' report, titled "Radioisotope Thermoelectric Generator," claimed the battery based on these principles should last 20 to 30 years, and suggested its application in a satellite. (The Vanguard battery is reported to have a life expectancy of about three weeks.) Mr. Briggs cited the availability of radioisotopes in kilocurie quantities and the development of high efficiency thermoelectric materials as factors which make possible the new unit.

A prototype of the battery is being constructed at the ADC, he reported. Its physical size will be comparable to that of a standard No. 6 dry cell (roughly 3 in. in diam and 7 in. high), with perhaps a little more weight, he said.

Push for Lithium

LAST month, American Lithium Institute President Marshall Sittig announced that the Institute had established its first two research fellowships, one at Massachusetts Institute of Technology, the other at Pennsylvania State University. This milestone, said Sittig, marked the end of the Institute's four-month organizational period and the start of its program "to direct, support, and correlate research on lithium."

One of the most promising metals in the Periodic Table, lithium has been a long time living up to its promise. The formation of the American Lithium Institute, with headquarters at Princeton, N. J., last November and its concomitant program are designed to push it along.

Hot and Cold: While the program will be devoted to research and development of all possible applications of lithium, the following four areas should prove of particular interest to missile men:

- High energy fuels. The use of metallic lithium and lithium compounds as

JET PROPULSION

high energy fuels and fuel additives is regarded as one of the hottest applications of the metal now under development.

- Nuclear coolant. The use of metallic lithium as a heat exchange medium for airborne nuclear powerplants also appears promising. Lithium is considerably lighter than present heat exchange mediums, sodium and water. Unanswered and important is the question of the metal's corrosion characteristics.

- Lightweight alloys. While application of lithium as a structural material is definitely limited, said Sittig, it is reasonable to consider its use as an alloying element in structures not exposed to corrosive atmospheres, e.g., cockpit enclosures.

- Ceramics. Scientists have found that lithium can be used to modify ceramics to get zero thermal expansion coefficients. What was being done with this knowledge, Sittig didn't know; but, as he pointed out, "It is of obvious interest."

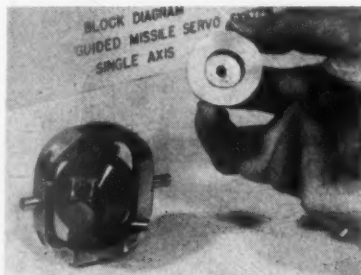
Selling lithium on a large scale has proved to be a tough job because the extremely reactive metal has been difficult to handle. Filling in some of the unknowns could make the task much easier; and, concedes Sittig, the metal's potential value to the missile industry won't hurt a bit.

Sperry Opens New Lab

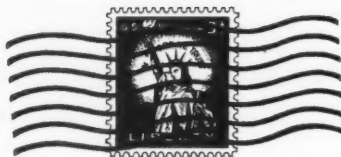
An environmental testing laboratory for tiny precision missile devices which get their energy from small charges of solid rocket propellants was recently completed by the Sperry Gyroscope Co.'s Air Armament Division.

Situated in one corner of the firm's Nassau plant in Great Neck, L. I., the new 4000-sq ft building is believed by the company to be the only one of its kind wholly devoted to this type of development work. Test bays in the monitor-style lab include an altitude testing chamber, a vibration and acceleration testing room and a shock testing area, plus more conventional facilities.

A number of devices which use gases



Nitroglycerin-based doughnut of fuel for gyroscope device about to be assembled in Sperry Gyroscope's new lab.



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from the detonated fuel either immediately or over a longer period have been taken past the developmental stages by the company. Featured among these units, all of which are used for missile guidance or control, is a gyroscope in which the gyro can be blasted up to 50,000 rpm in 0.2 sec or less, according to Sperry. The charge is a small doughnut of black nitroglycerin-based propellant.

Other companies are known to be working with propellants as auxiliary power sources within missiles. Most of the effort has been with solid fuels, although Sperry says it contemplates experimenting with liquid propellants.

Directing the over-all missile devices program for Sperry is John R. Ericson. M. Russell Hannah is in charge of the new laboratory and its dozen engineers and technicians.

Bladder Bids for Missile Use

BACKGROUND: The use of pressure to move liquid propellants from storage tank to combustion chamber is standard practice in missile engineering. Separation of the pressuring gas from the propellant by use of a nonporous, flexible bladder in the storage tank is not essential. But engineers have found it does have many advantages. The problem has been to find a perfect bladder—one that will remain flexible, impermeable, and strong over a two-year storage period, in a corrosive environment, and under extreme temperatures and temperature changes.

THE ideal propellant expulsion bladder doesn't exist. So say propulsion system engineers, and they have been looking a long time.

Prompted by this prolonged quest of the missile engineers, Joclin Manufacturing Co., Wallingford, Conn., decided three years ago to join the search. Now the company believes it has struck paydirt, reports that it has gone into production on a propellant bladder made of Teflon fluorocarbon resin.

The company doesn't claim its bladder is the ideal one, but does believe it is better than anything else now available. Backing this claim is the interest in this unit now being shown by some top U. S. missile makers.

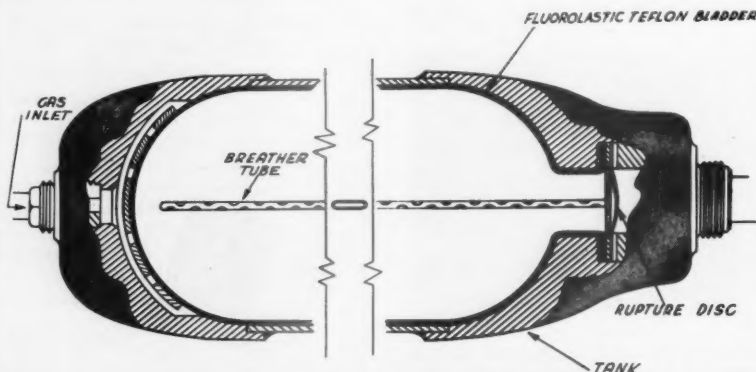
The bladder has already found a place in two new ramjet missiles where it will be used in the storage tanks holding the igniter liquid for JP fuel. This setup, the engineers hope, will replace electrical ignition systems subject to failure under environmental extremes found in

most newer missiles now on the scene.

Seamless Sausages: In appearance, a typical Joclin bladder looks like an empty sausage casing with a neck at one end. At present, the seamless bladders are available in a variety of shapes up to 10 ft long by 3 ft in diam. In addition to being flexible and tough, according to Joclin, the bladders are serviceable at operating temperatures ranging from -450 F to 550 F, impermeable to all corrosive chemicals and solvents except molten alkalis and hot fluorine, and have high dielectric strength.

What the company hasn't had a chance to find out yet is how the Teflon bladders will stand up to liquid oxygen. Nor is it known just how long and to what degree the impermeability will last under extended storage periods.

But if the bladders perform as well as the company expects them to, or even close to it, said one rocket engineer, "We and practically everybody else in the field are definitely interested."



Propellant Bladder: Some questions still unanswered

JET PROPULSION

Jet Propulsion News



Titan Test Stand

Under construction near Denver, this test stand will be used by the Glenn L. Martin Co. for static testing of the Titan ICBM. At its new Denver location, Martin has already completed the engineering and manufacturing buildings, reports that the test facilities are "at an advanced stage of construction."

MISSILES

- Second firing of the Army Jupiter may be near, say reports. The firings may be the result of a program which was in effect before the new missile policy. Other reports say that Jupiter may be continued under Air Force aegis.

- Photos of the Lockheed X-17 indicate that this re-entry research vehicle may have been the missile which flew 3000 miles in a firing last September. First stage of the X-17 is said to be a modified Redstone; second stage, a cluster of three Sergeants; and the third stage, a single Sergeant solid propellant rocket.

- Firestone is developing a new launcher for firing the 7-ton Regulus from the subs Grayback and Growler.

- According to the Defense Department, atomic warheads are now arming air-to-air missiles and will soon arm air-to-ground missiles. While the Department did not name the air rockets, it did say that nuclear tips can be used on the Nike-Hercules and the Talos.

- In a recent demonstration at China Lake, a Sidewinder missile knocked out a target plane. For guidance, the Navy missile uses an infrared seeker that is unable to differentiate between friend and foe.

- A high-flying XQ-2B Firebee target drone has set an altitude record of 53,000 ft at Alamogordo, N. M. The XQ-2B is powered by an improved J-69 turbojet and has a wing area one-third larger than old models. Navy and Air Force contracts for the Ryan target craft now total \$5.25 million, and the company recently announced that it had also received a \$10-million contract from the Air Force for the drone.

- First U. S. missile that will be used by Britain is the Corporal. A guided weapons regiment was to be formed in March to be trained in the U. S. Standard or nuclear warheads will arm the missiles.

- The Air Force has activated the 589th Tactical Missile Group at Orlando AFB, Fla. Fifth of the tactical groups to be activated, the 589th is equipped with the TM-61B Matador.

- The 500th flight has been made by the Chance Vought Regulus I.

- To better handle the several large government programs recently awarded Lockheed's Missile Systems Div., the company has announced that it will integrate the division's research and engineering under Louis N. Ridenour, present director of research. Among the most important of these new programs is

the Polaris, the new Navy IRBM for which Lockheed is prime missile system contractor.

- Secretary of Defense Charles E. Wilson has delayed execution of his decision giving the Air Force control of the Army's IRBM Jupiter.

- Also delayed has been the court martial of Col. John Nickerson, Jr., senior officer of the Army Ballistic Missile Agency. In his attack on Wilson's Jupiter decision, Col. Nickerson issued a memorandum to newsmen and other unauthorized persons in which, it is charged, he disclosed classified information. Col. Nickerson's attorneys have needed time to prepare their defense, expect the court martial to take place some time this month.

- Meanwhile, reverberations of another Wilson decision—combining the jobs of the Assistant Secretary of Defense for Research and Development and of the Assistant Secretary of Defense for Engineering under Frank Newbury, Assistant Secretary for Engineering—are still being felt. Scientists feel this will give the engineering viewpoint dominance in future Defense Dept. decisions concerned with new weapons development. Opening the way for this move was the recent resignation of Clifford C. Furnas, who headed R&D, to return to his job as chancellor of the University of Buffalo.

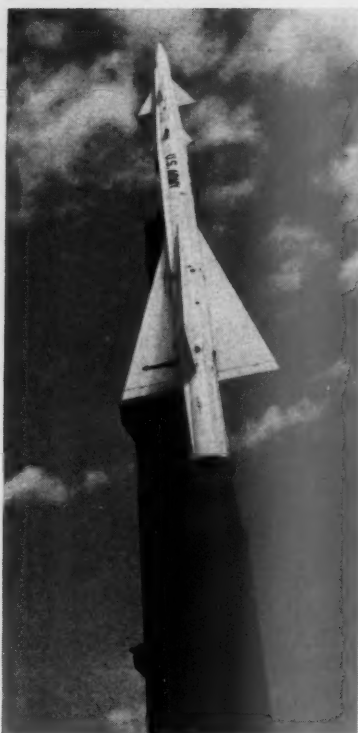
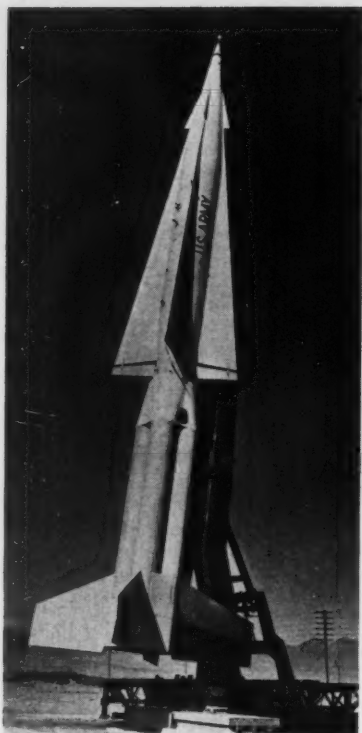
- Reportedly too small for its intended use as a surface-to-air missile, the Loki has been renamed the HASP (high altitude sounding projectile) and will be used by the Navy to collect weather data from altitudes up to 20 miles.

- Brig. Gen. Hollingworth F. Gregory, director of the Air Force Office of Scientific Research, was quoted in a press dispatch as saying that within five years the Air Force may launch a moon rocket.

- In another dispatch, Lee De Forest, inventor of the vacuum tube, has been quoted as saying that man would never reach the moon "regardless of all future scientific advances."

- An Army spokesman has predicted that all Army divisions will be "pen-tomic"—five combat groups with atomic weapons instead of three regiments—divisions within 18 months. The new divisions will be equipped with Honest John and Little John missiles.

- Last month, a Jupiter launching at Patrick AFB reportedly misfired. There were no casualties.



Ajax vs. Hercules

Designated Nike-Hercules, the new version (left) of the Nike surface-to-air guided missile is now undergoing final tests.

Compared to the first version (right), now designated Nike-Ajax, the new missile will be longer, heavier and more than twice as great in diameter. It will also be faster and have a greater altitude capability. Range of the new missile is reported to be at least 50 miles, more than twice that of the Ajax. And, according to a Defense Dept. statement, Nike-Hercules will have nuclear capability.

With certain modifications in present ground control equipment, the new Army missile can be integrated into the existing Nike batteries that now ring the nation's key industrial and metropolitan areas.

- Rocketdyne has been awarded contracts totaling more than \$1.5 million for completion of test facilities at its new Neosho plant.

- Radio Corporation of America has announced the development of a "revolutionary" radar system that can instantly determine and evaluate behavior of guided missiles and satellites. Designated AN/FPS-16, the system, it is understood, will be among those that will be used in tracking the Vanguard satellite.

- It is reported that work on the nuclear-powered rocket has been sharply curtailed at the University of California's Livermore lab and at Los Alamos.

- Grand Central Rocket Co. recently revealed that it is developing a new static test center in Riverside County, Calif. Centered in an isolated 8000-acre tract, the new site, says the company, will accommodate the largest solid propellant rockets now on the drawing boards.

AIRCRAFT

- Boeing will install two Pratt & Whitney J-75 engines on the original XB-52 jet bomber for test purposes. The plane is presently equipped with J-57 engines.

While Boeing still has orders for about 350 B-52's, the government is said to be considering a faster replacement for the bomber. Defense Secretary Wilson said a decision will be made within the next few months.

- Air France has ordered seven additional Boeing 707 jet liners, raising its total order to 17.

- Chance Vought recently disclosed that it had begun a new design program for development of an advanced carrier-based fighter.

- Republic Aviation's F-84 Thundercraft have logged more than 3.5 million hours of flight time.

- After development of the F5D Sky-lancer to a production-ready status and production of a limited number of the

planes, Douglas Aircraft will suspend manufacture of the supersonic craft.

- It is reported that the Air Force plans to order mass production of Republic's F-105 instead of another fighter-bomber designed by North American.

- Hughes Aircraft claims that a new jet sound suppression chamber made by General Sound Control, Inc., has cut jet noise nearly 50 per cent at its Culver City (Calif.) plant.

- Sylvania is developing a universal digital operational flight trainer (UDOPT) under a \$1-million-plus Navy contract. The trainer will simulate characteristics of the latest jet fighters.

- Scheduled U. S. airlines are committed to purchase of more than half the 722 jet airliners ordered to date by airlines of the free world, the Air Transport Association states.



- Fiat reports that the second prototype of its G-91 lightweight jet fighter (photo) is nearly completed and a third one is on the way.

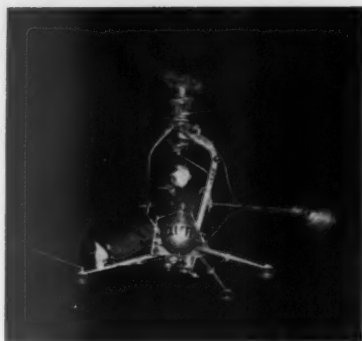


- Douglas Aircraft reports that its new self-contained refueling unit (photo) will make possible rapid conversion of Navy fighters and attack bombers into aerial tankers.



- Reason for the awkward-appearing elongated landing gear on the B-58 (photo), Convair says, is to keep the detachable pod from scraping the ground. This pod, declares Convair, makes the B-58 an extremely versatile and deadly weapons system.

JET PROPULSION



• Kellett Aircraft's rocket-powered Stable Mable helicopter (photo) recently made its television debut over NBC's "Tonight" program. The purpose was to demonstrate the helicopter's stability.



• Fate of Douglas' turboprop C-132 (see sketch), now nearing completion, is in doubt. The world's largest known cargo craft (up to 200,000 lb payload) reportedly has a low priority in USAF's fiscal 1958 budget. Present contract is a development one calling for production of only two C-132's.



• F.6 version of Hawker Hunter fighter (photo) is now in service with RAF.

• Westinghouse discloses the development of a new high temperature alloy composed of iron, nickel, chromium, molybdenum, titanium and boron. The material is intended for structural use in the turbine section of jet engines.

COMPANIES

• Bomarc will be produced in Seattle, according to Boeing, with limited support coming from Wichita, Kan.

• Aerojet's Avionics Div. will be expanded under an \$880,000 program at Azusa, Calif. (photo at right).

• First two buildings to be completed by Aerophysics Development Corp. (Santa Barbara, Calif.) are for engineering and research.

• New electronics lab for research in microwave physics and development of advanced radar and missile instrumentation will be located at a new \$2-million plant at Clearwater, Fla. The lab will operate as a division of Sperry Rand Corp.

• Gulton Industries (Metuchen, N. J.) is setting up a new division for work in high frequency telemetering systems.

• Expansion of its corrosion research laboratory for work in the guided missile field was announced by Carpenter Steel Co. (Reading, Pa.).

• Acquisition of National Electronics Laboratories, Inc., Washington, D. C., was recently announced by Thiokol Chemical Corp.

• Two new weapons systems organizations have been established by Lockheed's Missile Systems Div. in Palo Alto and Sunnyvale, Calif.

• RCA has established electronics engineering operations at White Sands for work in missile electronics, ground support systems, missile guidance and missile launching systems.

• Over \$1 million will go to North American Aviation for additional work on the SM-64 Navaho missile.

• Pratt & Whitney Aircraft will operate its nuclear engine program as a separate operation at the Air Force facility in Middletown, Conn.

• Production of safety and arming mechanisms for Nike is being stepped up by 200 per cent, says Elgin National Watch Co., at company plants in Elgin, Ill., and Lincoln, Neb., under a \$360,000 contract.

• Associated Missile Products Corp. (Pomona, Calif.) has received a \$19.5-million guided missile instrumentation contract from Martin Co.'s Denver Div.

• Two new divisions of Sperry Gyroscope Co.—an Air Armament Div. and a Surface Armament Div.—were announced. The new divisions will center their engineering and manufacturing

efforts at Lake Success, N. Y.

• The Staff New Devices Dept. of Thompson Products (Cleveland) will move into the company's new \$26.5-million Research and Development Center. The department is engaged in R&D efforts in the missile field.

• Pratt & Whitney announces that it will take part in the joint government (National Bureau of Standards)-industry project to make accuracy to 0.0000001 in. possible in measurements.

• Stauffer Chemical Co. has developed a new process for producing titanium metal that may be applied also to the production of other metals such as columbium, tantalum and zirconium.

• Avion Div. of ACF Industries has received two new contracts for continued development of guidance and control systems for the Sidewinder.

• New Departure Div. of General Motors is sponsoring an Aircraft Ball Bearing Symposium, April 16-17, at the Hotel Statler in Hartford, Conn.

• Kemsco, Inc., reports that almost all of its efforts are being devoted to produce equipment for handling large quantities of liquefied gases for the missile industry. Production of lox and nitrogen pumps is being made at the firm's Santa Barbara (Calif.) plant.

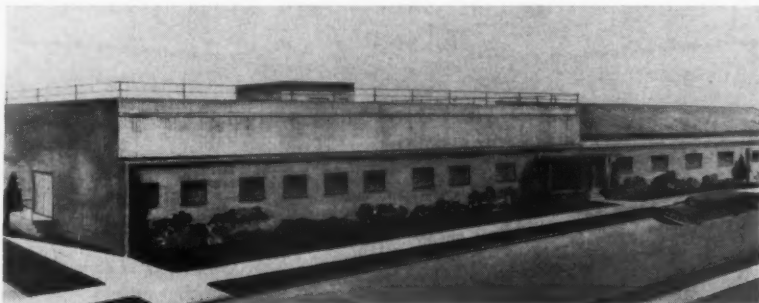
• An additional contract with Convair Astronautics will push its backlog for guided missile test equipment to \$3 million, says Siegler Corp.'s Hallamore Electronics Div., Anaheim, Calif.

• Ground was broken for a new Summers Gyroscope Co. plant in Santa Monica, Calif. The unit will manufacture guidance instruments and systems for missiles and target drones.

• Applied Science Corp. (Princeton, N. J.) has acquired a 150-acre site near its headquarters for a plant to produce telemetering equipment.

• Scientific Instruments Div. of Beckman Instruments has plans for a \$1.5-million R&D building at Fullerton, Calif.

• Acquisition of Honeycomb Structures Co. (Los Angeles) was announced by Swedlow Plastics Co. The new Core



Div. will make aluminum-foil honeycomb.

- Also entering the aluminum honeycomb field, L. A. Young Spring & Wire Corp. (Detroit) has purchased the Flexo Mfg. Co. (Los Angeles).

- Instruments and power supplies for missiles will be built by Arnoux Corp. (Los Angeles) in a new addition to its plant.

- Norton Co. has broken ground on a new \$1.5-million refractories plant at Worcester, Mass.

- Douglas Aircraft has officially separated the aircraft and missiles engineering departments at its Santa Monica Div.

- Kaman Aircraft Corp. was awarded a Navy contract for the development of a new single-rotor utility helicopter, known as HU2K.1, which will be powered by a GE T-58 gas turbine.

- United States Chemical Milling Corp. will establish three new chemical milling facilities. One will be located in the Dallas-Fort Worth area, another in the Midwest, and the third on the East Coast.

- Callery Chemical Co. broke ground in Muskogee, Okla., last month, for construction of a \$38-million high energy fuel plant.

INSTITUTIONS

- AMERICAN ROCKET SOCIETY was one of the sponsors of 1957 Nuclear Congress in Philadelphia. Topics discussed were nuclear fuels, heat transfer, metallurgy, control and operation of reactors.

- On April 29, the Third Flight Test Instrumentation Symposium will meet in Los Angeles. Topics of missile interest: Over-instrumentation, correlation of static and flight test data, and techniques of power spectro density.

- Southern Research Institute (Birmingham, Ala.) will sponsor a two-day symposium on "The Age of Space." Meeting is scheduled for May 16-17 in Birmingham, will include a trip to Redstone Arsenal on the 17th.

As now planned the symposium will cover the following topics: Military

and civilian research, fuels for space vehicles, Project Vanguard, description of a hypothetical trip to Mars, space medicine, comparison of U. S. and Russian missile technology, and materials for space vehicles.

Among the featured speakers will be C. C. Furnas, Dan A. Kimball, John P. Hagan, Ernst Stuhlinger and Maj. Gen. Dan C. Ogle.

FOREIGN

England: Britain's aircraft and guided missile industry remains on tenterhooks while Defence Minister Duncan Sandys makes up his mind as to the new shape of Britain's defense forces.

The quandary in England, and to a certain extent everywhere else near Russia, is whether air defense is worthwhile when penetration by a few bombers or missiles with megaton warheads can nullify all such efforts. It is widely accepted that 100 per cent defense is out of the question, even against manned bombers.

And, ultimately, the threat to Britain would not be from manned bombers but from nuclear ballistic projectiles. "It is similarly clear that the future effectiveness of our deterrent power will also depend upon the possession by us of these weapons," Sandys has noted.

As British projects stand at present there are three ground-to-air missiles at an advanced stage (all have flown repeatedly), two air-to-air, at least one intermediate range ballistic missile that will probably have engines made by Rolls Royce, possibly under North American license, and some ground-to-ground antitank and short range tactical weapons. These, but not the IRBM (very early stage) have all flown.

- On February 15 came news that British and French missile men were to meet "shortly" to draw up a list of modern weapons on which the two nations could collaborate. There has so far been little exchange of missile information with the French. Herr Strauss, the West German Defence Minister, it will be recalled, has already been shown the French testing grounds at Colomb-Bechar in the Sahara. The Germans

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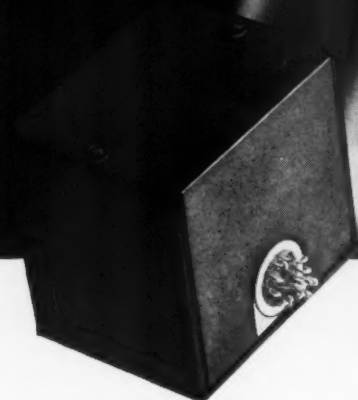


Double Trouble

These two high speed Ryan Firebees slung under the wings of a B-26 spell trouble for the Air Defense Command.

The recently formed 4750th Drone Squadron at Vincent AFB (Yuma, Ariz.) uses the Firebees to simulate enemy aircraft in probing for weak spots in this country's air defense.

AiResearch servo- controller for a pilotless guidance system



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The servo-controller can operate from either a DC or AC power supply. It can also be designed to take signals from celestial, telemetering or pre-programming sources to maintain or

readjust the course of its pilotless air vehicle. It is another example of the AiResearch Manufacturing Division's capability in the missile field.

Inquiries are invited regarding missile components and sub-systems relating to air data, heat transfer, electro-mechanical, auxiliary power, valves, controls, and instruments.

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are said to be interested in a French wire-controlled antitank rocket and have one of their own they would like to sell.

- From Australia has come word that the British high altitude research rocket Skylark has been given its first flight test. The vehicle, powered by Raven solid fuel motor, was fired from its 80-ft launching ramp at a low angle. It rose to a height of 50,000 ft and landed 20 miles away. This experimental firing was hailed by Australian Defence Minister Howard Beale as a "complete success."

- London's *Daily Telegraph* reported on February 28 that U. S. bases for heavy bombers in Britain would probably be allowed to install Nike-Hercules to protect planes of Strategic Air Command.

France: Main features of French military reforms announced after a visit of Defence Minister M. Bourges-Manoury to London on February 14, included the "constitution of a highly mobile 'intervention force' that would be equipped with direct support missiles and would make increasing use of guided rockets and ground-to-air weapons."

Germany: London's *Daily Worker* on February 25 reported that the Hesse (West German) Provincial Government had refused consent for the construction of an American rocket base. The U. S. Government had already received permission from the Federal Government War Ministry to set up Nike bases in Hesse-Rheinland palatinate and Baden-Wuerttemberg. The Hesse Govern-

ment is reported to have stated that such bases constituted a peril to the local population for which it was not prepared to answer.

RESEARCH & DEVELOPMENT

- D. J. Lovell of Allied Research Associates, Inc. (Boston), and G. R. Miczaika of Harvard College Observatory have developed a new device that they hope will enable astronomers to see through the interstellar dust clouds that usually obscure the center of the galaxy. The instrument is called an infrared stellar photometer.

- Chicago Midway Laboratories, under a subcontract from General Electric Co., has developed a water-stabilized electric arc that can create temperatures to 25,660 F, more than twice the temperature of the sun's surface. The new arc, said GE's Leo Steg, will lessen the need to build giant hypersonic wind tunnels for test purposes.

- The Army will build a solar furnace capable of creating temperatures comparable to those generated in an atomic explosion, at the Quartermaster Research and Engineering Center, Natick, Mass.

- Army Map Service plans to use radio data from the Vanguard satellite to pinpoint island locations on maps and navigation charts.

- Yusuf A. Yoler, manager of aerodynamics in General Electric's Missiles

and Ordnance Systems Dept., has received a patent (No. 2,783,684) on a gun that uses a chain of electric arc discharges instead of a powder charge to discharge a projectile.

- The 1000 hp Saturn T-1000S gas turbine powerplant weighs 500 lb, says the manufacturer, Solar Aircraft Co. The engine is 5 ft long, 2 ft wide and 2 ft deep. Operation is 2000 hr between overhaul. The Saturn will be used by the Navy to power new types of landing patrol craft.

- Curtiss-Wright's ATO rocket uses gasoline and lox. Thrust is about 4000 lb for 60 sec. Empty weight is said to be around 680 lb. Length is 132 in.; diameter, 32 in. (max.). Throttleable C-W engine for the Bell X-2 had an output thrust of about 12,000 lb.

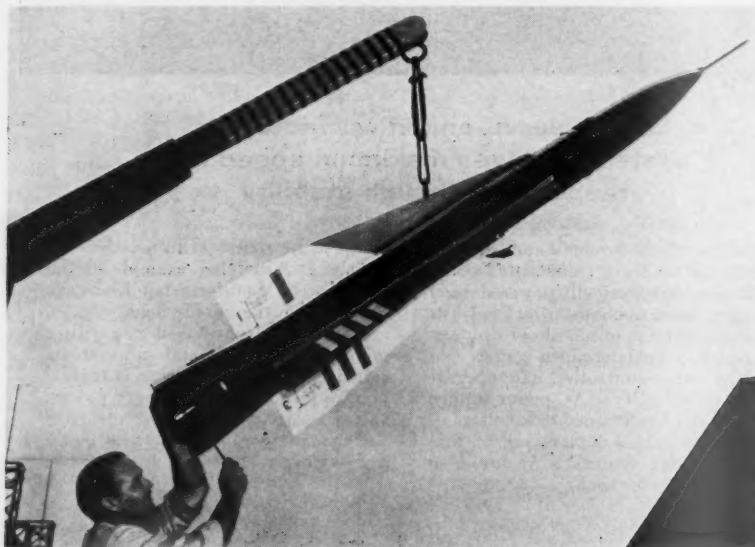
- Velocities of 25,000-50,000 fps are the goal of a new Armour Research Foundation project for the Air Force. Electromagnetic principles will be applied to the design of a high velocity linear accelerator to study impact, air friction, and ablation factors of great interest in designing missiles.

- A supersonic combustion laboratory is under construction by Fairchild Engine Div. at Deer Park, L. I., N. Y. The lab will be used in experimental work in the fields of aerodynamics and thermodynamics for the Air Force Office of Scientific Research.

- Minitrack, Naval Research Lab's tracking device for the Vanguard satellite, is being built by Bendix. The 13-oz transmitter in the satellite—operating at a power of 10-15 milliwatts on a frequency of 108 mc—will beam its signals to Minitrack on ground stations. Each Minitrack receiving system will occupy six racks, each about the size of a filing cabinet. Each system will be housed in an air-conditioned mobile trailer and receive signals from eight antennas at each station. Twelve stations will be used to pinpoint the position of the satellite.

- Those volunteers for space crews who are worried about getting hungry on long interplanetary voyages may now rest easy, according to National Research and Development Corp. (Atlanta, Ga.). The company has developed a new bulk-providing concentrated food called Multi-Meal-Tube "in anticipation of the advent of... extended periods of flight."

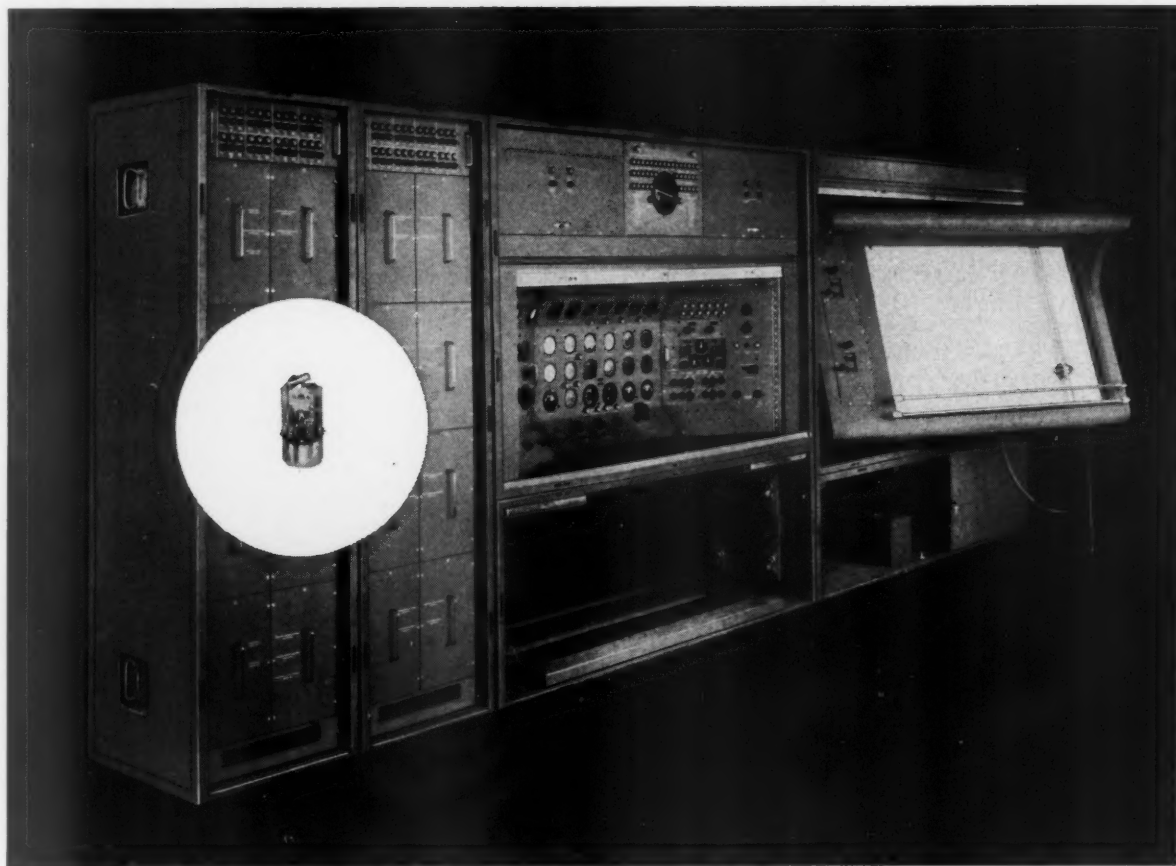
The semisolid concentrate is contained in a metal tube "so designed that the plastic cap may be removed with one hand and the contents squeezed therefrom directly into the mouth, thereby... leaving one hand free for performance of piloting procedures, etc." Not, perhaps, as palatable an arrangement as a copilot and steak, it certainly seems to be a convenient one.



Backward Missile

As part of an Air Force-sponsored program to develop a missile capable of being fired by bombers against attacking fighters, Cornell Aeronautical Laboratory designed an unusual system to control a rearward-launched BDM (bomber defense missile), then developed the above experimental missile to test the system.

The basic BDM concepts, says CAL, have been turned over to industry for further development.



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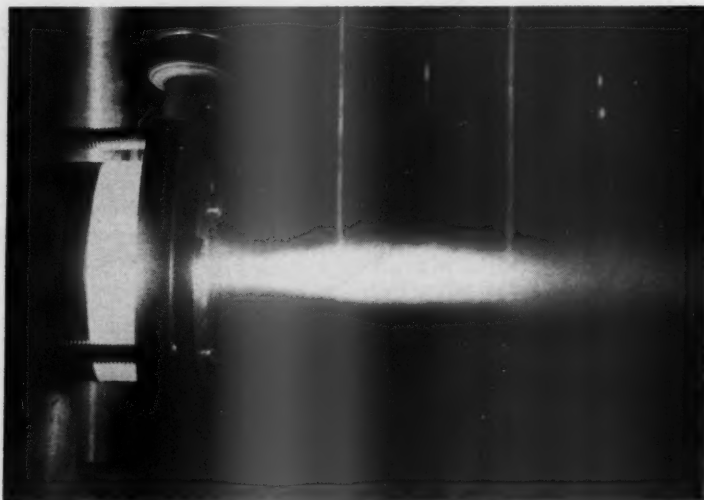
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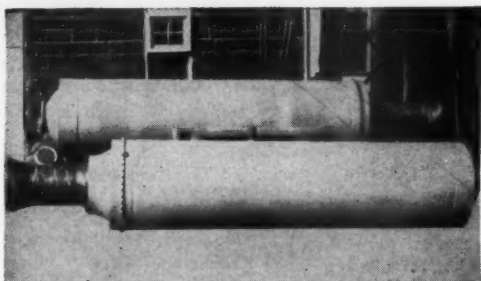
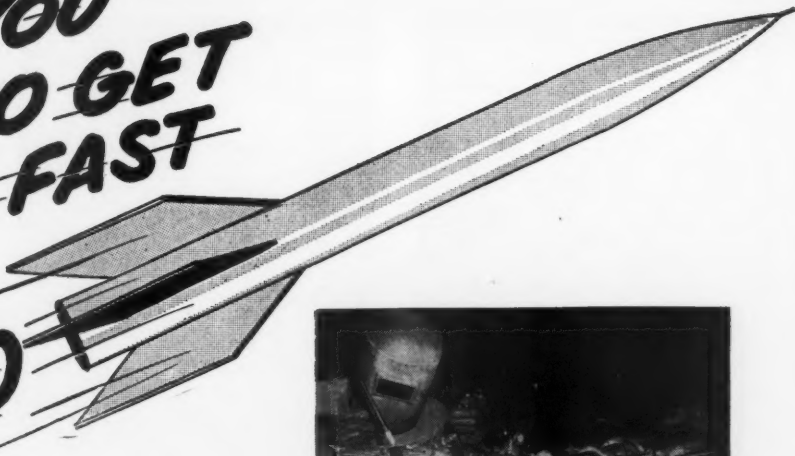
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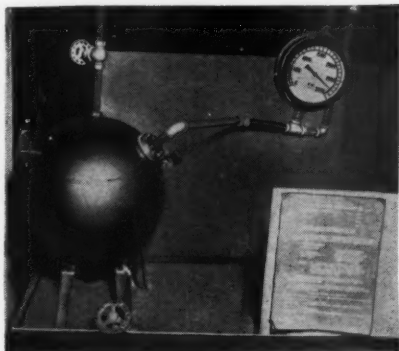
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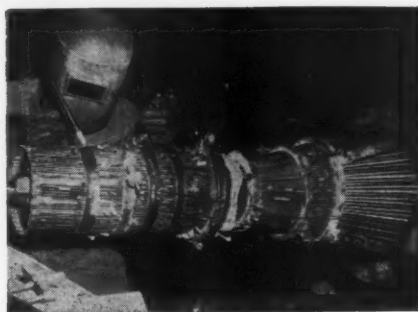
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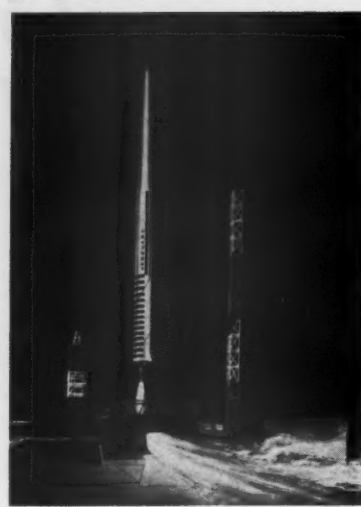
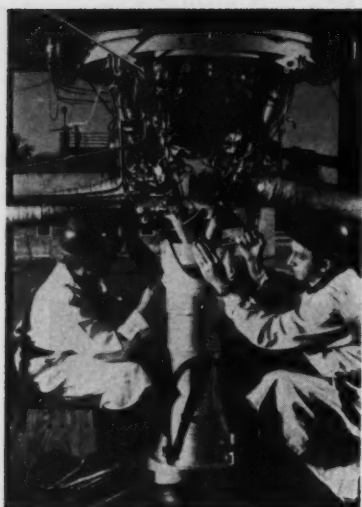
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Vanguard Progress Report



With the first satellite attempt now placed in January 1958, Project Vanguard is nearly on schedule.

The X405 engine (left) for the first stage is set for delivery to Martin. The General Electric engine is designed to deliver over 27,000-lb thrust for about 150 sec. Burning a hydrocarbon fuel and liquid oxygen, the engine features advanced components,

including turbopump and thrust chamber. Martin's Plant No. 1, near Baltimore, has a new vertical test stand and check-out tool for Vanguard (center). Martin recently flew Viking No. 13 in a Vanguard test at Patrick AFB, Fla. New photo at right shows latest concept of Vanguard launching. Note erection tower in background, firing platform, and cable tower in foreground.

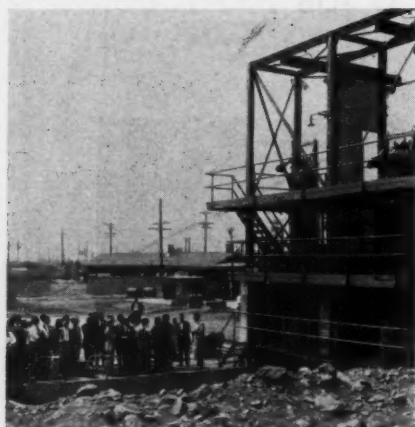
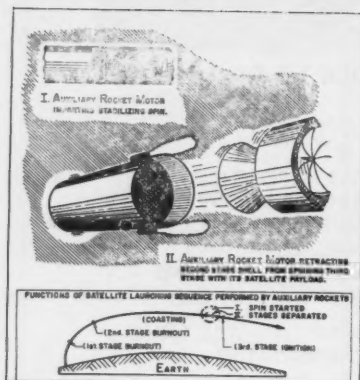


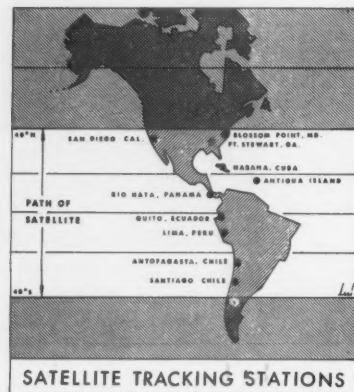
Photo at left was taken at a subcontractor's presentation at Aerojet's Azusa plant. The test stand was built especially for testing of a complete second-stage powerplant.

The table at the right compares the second-stage performance with the Aerobee-type rocket. Notable differences are higher performance, high-altitude ignition, and thrust vector controls.

Parameter	Aerobee rocket	Second-stage Vanguard
Burnout velocity	1.35 mile/sec max	>1.95 mile/sec
Size	standard	greater length and diam
Total thrust	4100 lb	higher
Duration	53.1 sec max	longer
Ignition	low altitude	vacuum
Propellants	RFNA & aniline-alcohol mixture	nitric acid & UDMH
Propellant feed	pressurized system	pressurized system
Guidance	none	inertial guidance for whole satellite
Thrust vector control	none	gimbaled thrust chamber
Attitude control during coast	none	jet control



Atlantic Research Corp. solid propellant rockets (left) will spin and separate the third stage. The first polished, gold-plated satellite has been completed by Brooks & Perkins (center). NRL has already received two "rough" shells for structural tests. The first two polished shells will also go to the Navy for



testing but may eventually wind up atop the Vanguard rocket. Some 20-25 other gold balls will be delivered in the near future. Meanwhile a belt of satellite tracking stations is now being established (right) to collect data on the satellite trajectory during the upcoming International Geophysical year.

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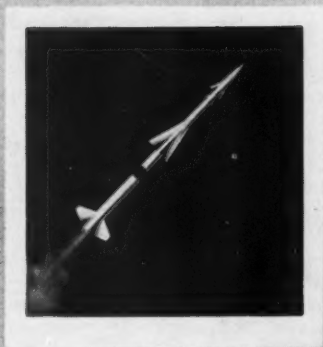
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Space Flight Notes

JOHN GUSTAVSON, Convair-Astronautics, Contributor

Speaking of Space Flight. . .

WHILE possible timetables for space conquest and the means for achieving it were responsible for most of the newspaper and magazine headlines arising out of the first Space Flight Symposium, hard-headed participants at the conference showed more interest in present developments than in theoretical future possibilities.

That interest in space flight is growing by leaps and bounds was indicated by the attendance of some 600 engineers and scientists at the symposium, held in mid-February at San Diego and sponsored jointly by the Air Force Office of Scientific Research and Convair-Astronautics Div. of General Dynamics Corp.

The large attendance, considerably greater than had originally been anticipated, provided strong proof of the increasing attention being focused on the possibilities of space flight by industry, the military and universities throughout the country. Present indications are that the symposium may be repeated next year at another location.

In their addresses opening the symposium, Gen. Joseph T. McNarney, president of Convair, and Brig. Gen. Hollingsworth F. Gregory, commander, AFOSR, emphasized the interest now being shown in astronautics by industry and the Air Force respectively. Maj. Gen. Bernard A. Schriever, commander, Western Development Div.,

Air Research and Development Command, emphasized the prestige to be gained by undertaking lunar expeditions and interplanetary flight, during a speech at the symposium dinner meeting.

The three-day symposium was broken down into six panel meetings, covering re-entry, tracking and communications, environments and measurements, propulsion, orbits, and human factors; a classified session; and a summary session presided over by Theodore von Kármán, AGARD, covering the main points discussed at the panel meetings. Each panel was made up of approximately eight members and a chairman, selected by Marvin Stern of Convair, who also made the over-all arrangements.

A brief summary of the six panel meetings follows:

RE-ENTRY

Chairman: William H. Dorrance, Convair

During this session, it was evident that panel members had enlarged the concept of re-entry, which is no longer taken to apply only to the problem posed by entry into the earth's atmosphere of a ballistic missile or a descending satellite ferry rocket, but also to the universal problem of entering *any* atmosphere. The atmospheres of the

planets Mars, Venus and Jupiter were consequently discussed to some extent. It was pointed out that the atmosphere of Mars probably consisted of 98 per cent nitrogen and 2 per cent carbon dioxide. Jupiter's atmosphere consists of large amounts of hydrogen, with some helium in addition to five other hydrogen compounds.

The problem of re-entry—or perhaps more correctly, entry—into Venus' atmosphere is similar to that of the earth. The same gases can be found in the highly excited shock, and the variation of density with altitude is almost the same.

Panel members found that knowledge of the atmospheres of the planets is inadequate, and that much information is needed about the earth's atmosphere above 100,000 ft.

Speakers also dealt with the re-entry of pure drag bodies, the decelerations introduced, and the reduction of these forces by the employment of lifting surfaces.

TRACKING AND COMMUNICATIONS

Chairman: Clark A. Potter, Navy Electronics Laboratory

This session dealt with the problem of transmitting a signal over large distances in space when considering the limited power available in a space ship. CW systems, or perhaps only pulse techniques, will be employed. Steerable antenna systems are necessary. Such systems, on the other hand, require attitude control. The antennas will be huge, very frail structures, capable of withstanding only low accelerations.

A navigation system based on the use of radio stars was outlined. Together with an accurate cesium or ammonia clock, radio stars of this type will furnish a position line for the space vehicle. The sun was mentioned as the nearest radio star, with Cygni A regarded as a more reliable source of transmission.

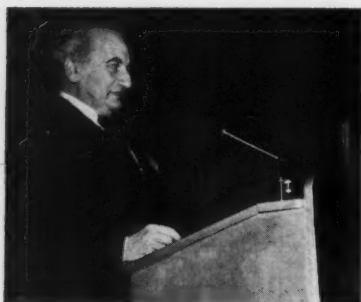
A tracking system to be used together with the Minitrack during the International Geophysical Year was also described. The Microlock is said to have a range from 2500 to 15,000 miles and be capable of working over a period of several months.

PROPULSION

Chairman: William Bollay, Aerophysics Development Corp.

This session covered a number of advanced propulsion systems. Too much attention appeared to be given to purely theoretical power sources, like fusion

JET PROPULSION



Theodore von Kármán presides over the summary session.



At the dinner meeting are (l to r) C. L. Critchfield, Convair; Maj. Gen. Bernard A. Schriever, Gen. Joseph T. McNarney, Convair president, and Morton Alperin.



Going over an important point are (l to r) Charles L. Critchfield, K. J. Bossart and Krafft A. Ehrlicke, all of Convair.



William H. Dorrance of Convair at the rostrum, with Theodore von Kármán (center) and Morton Alperin, AFOSR.



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processes for the photon propulsion system. Ionic propulsion was also treated, and appeared promising for interplanetary flight.

The major problem with this and other electric propulsion systems is the heavy weight of the power unit. Both solar and nuclear power generators are very heavy—the solar generator because it employs huge collectors to concentrate the radiation energy from the sun, and the nuclear generator because shielding material is necessary.

It was disclosed, however, that two companies in this country already have contracts pertaining to ion propulsion. It was later learned that these companies are Avco and Rocketdyne. Aerojet may also have a contract by this time.

Giannini Research Laboratory, Santa Ana, Calif., has conducted some experiments with arc chambers. Electric arcs have been tested with up to 50 kw power input. By conducting argon or helium through the arc, some of the energy is transferred to the gas. By expanding the gas through a nozzle, very high exhaust velocities can be obtained. The efficiency, however, is low, since a good deal of heat is conducted away to the chamber. The propulsion aspect is not promising, but arc chambers may be used for advanced wind tunnel facilities.

Robert Truax, president of the AMERICAN ROCKET SOCIETY, outlined the importance of revising chemical powerplants when applying rocket engines to space flight. As an example, he pointed out that low chamber pressure may be used, thus saving weight.

ENVIRONMENTS AND MEASUREMENTS

Chairman: Fred L. Whipple, Smithsonian Astrophysical Observatory

Recent investigations of the ionosphere have disclosed that the concept of definite ionized layers is not exact. Only a slight change in the electron density has been observed. The E-region is formed by 20 Angstrom x-rays, which correspond to gray-body radiation from a 700,000 K source. Shorter wavelengths have been detected (down to 3 Å) which may penetrate down to 75 km and double the D-region.

Meteorites will—after the latest calculations—penetrate the earth satellite at a rate of one every four days. At the same time, the hull will constantly be eroded by meteoritic dust, pitting and abrading it at an unknown rate.

A proposal was presented dealing with the construction of a vacuum laboratory to simulate space conditions. Such an enclosed laboratory would offer conditions under which electronic research, temperature experiments and development of a space suit could take place. The audience showed considerable interest in the proposal.

ORBITS

Chairman: Paul Herget, Cincinnati Observatory

Powered and unpowered orbits in cis-lunar space were discussed and a thorough definition of the term "cis-lunar space" given. It is defined as that region of space in which the free motion of the space vehicle is no longer under the practically exclusive domination of the terrestrial gravitational field, but where the vehicle is also influenced to a significant degree by lunar and solar perturbations. The term "significant" is a function of mission requirement, and the transition between the adjacent terrestrial and the somewhat more distant cis-lunar space can therefore not be defined sharply. A good approximate boundary region is, however, the distance of two earth radii from the center of the earth.

The Vanguard program is believed to be yielding information which will improve such constants as the radius of the earth and the gravitational constant. It was pointed out that the tracking of the IGY satellite can be done with an accuracy of 2 in. The photographic data upon which this determination is made will, however, not be available until three hours after observation. This method can therefore not be employed for a lunar probe.

HUMAN FACTORS

Chairman: Dr. Hubertus Strughold, USAF School of Aviation Medicine

The effects of cosmic rays on living cells were found to be dangerous, if not lethal, for the cell. Emphasis was put on the fact that an increase of 35 per cent in the radiation reaching the earth could be expected when solar eruptions occur.

Drugs may be used to keep crews of space vehicles of the near future alert. Weight considerations limit the number of crew members, and the functions of each member will necessarily be multiplied. In a recent experiment, the effects of dextroamphetamine were analyzed. Pilots were treated at 9 a.m. and kept awake for 30 hours while enclosed in the cockpits of their grounded airplanes. Only short eating and exercise periods were allowed. The pilots were tested at regular intervals, and the results showed that the rate of reaction decreased from 12 midnight to a minimum at 6 a.m. Then it increased and reached half the initial value at noon.

Many of the participants of this first astronautics symposium were members of the AMERICAN ROCKET SOCIETY. If the symposium is repeated next year, the number of panels and topics will probably be reduced.

As the first meeting of this type solely devoted to space flight, the symposium marked a significant step forward in the advance toward interplanetary travel.

JET PROPULSION



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Satellite Details Revealed at ARS Spring Meeting

THE combination of ten outstanding technical sessions, important addresses by leading figures in the guided missile industry, and cherry blossom time brought more than 750 members of the AMERICAN ROCKET SOCIETY and their guests to Washington, D. C., early this month for the ARS Spring Meeting, held under the auspices of the National Capital Section.

One of the highlights of the meeting was the first presentation of full details concerning the design, fabrication, and testing of the earth satellite.

As author Robert C. Baumann of the Naval Research Laboratory pointed out, there have been numerous design concepts of earth satellites published. "It appears to be open season for space-minded individuals to design satellites," said Baumann. While such projects often reflect a healthy interest and considerable ingenuity, they seldom bear more than a passing resemblance to NRL's Vanguard satellite vehicle.

Round, Firm and Fully Packed: In contrast to most of the published satellite concepts, Project Vanguard was not created. Rather, it has evolved through numerous theoretical, design and test stages. Now the pre-launch part of the program is in its final phase and the vehicle is essentially in its finished form. And this, according to Baumann, is what it looks like:

It is a sphere 20 in. in diam, made of FSI magnesium alloy with a highly polished coat of silicon monoxide. Coming off the sphere at the equator are four antennas mounted 90 deg apart. Tubular rods fasten the antennas to a tubular ring which is concentric with a cylindrical inner package.

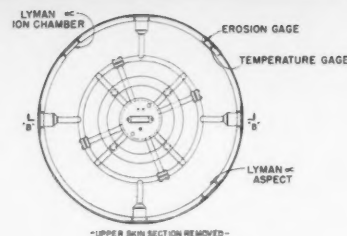
Four bow-shaped, vertical, tubular members, spaced 90 deg apart and at 45-deg angles to the antenna supports, also brace the concentric tubular ring. The four bows, in turn, are fastened to the support ring of the access port at the top, and to the main support column, which houses the separation mechanism, at the bottom.

The cylindrical internal package is mounted on the main support column and is secured to the concentric tubular ring by four low thermal conductivity, radial supports, spaced 90 deg apart and angularly positioned between the antenna supports and the vertical members.

Inside the package are five 3/4-in.-thick modules: One for the Minitrack transmitter and associated electronic equipment, one for the Lyman alpha electronics and batteries, one for the



OUTSIDE AND IN: Illustrations (above and right) show latest concept of how earth satellite will look as it follows its orbit through space.



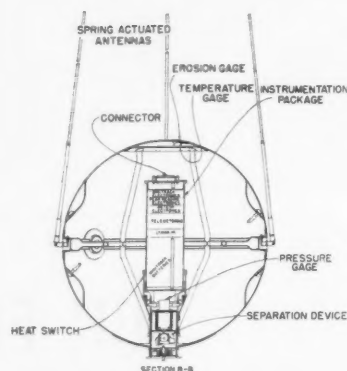
coding 48-channel telemetering system, one for the peak memory orbital switch unit, and one for the meteor counter. Below these five are two more modules for battery packages. All seven modules are fastened to the top cover of the internal package by two 1/4-in.-diam rods.

On the top cover of the internal package are the connectors—one 36-pin connector, one 14-pin connector, one 50-ohm microdot connector and two stand-offs for the Lyman alpha experiment. The connectors serve two purposes: (1) They connect the gages on the skin to the electronic equipment, and (2) they connect the electronic equipment to the batteries, thus acting as a turn-on switch.

On the shell are four microphones, a Lyman alpha solar cell, and a Lyman alpha ion chamber. In addition, there are erosion gages and temperature gages which are located both at the north pole area and around the equator. Then there is a pressure gage which is located on the vertical axis underneath the main package, and two pressure zones or bands that girdle the sphere above and below the equator.

Getting It Up: Altogether this satellite package will weigh only 21 1/2 lb. But it will take a three-stage rocket, approximately 72 ft long and weighing over 10 tons, to place it in an orbit 200 miles to 400 miles above the earth.

The first stage will be a liquid propel-



lant rocket with a 27,000-lb thrust. The second stage, also a liquid propellant rocket, will attach to the forward end of the first stage, will house the third stage and satellite, and will contain the "brains" for the entire launching vehicle. The third stage will be a solid propellant rocket upon which the satellite separation mechanism will be mounted. And on top of the separation mechanism, of course, will be the satellite itself.

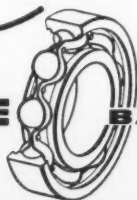
After launching, the vehicle will go through a short vertical flight and then start a zero-lift trajectory. Approximately midway through this zero-lift phase, the first stage will burn out, and the second stage will separate and ignite.

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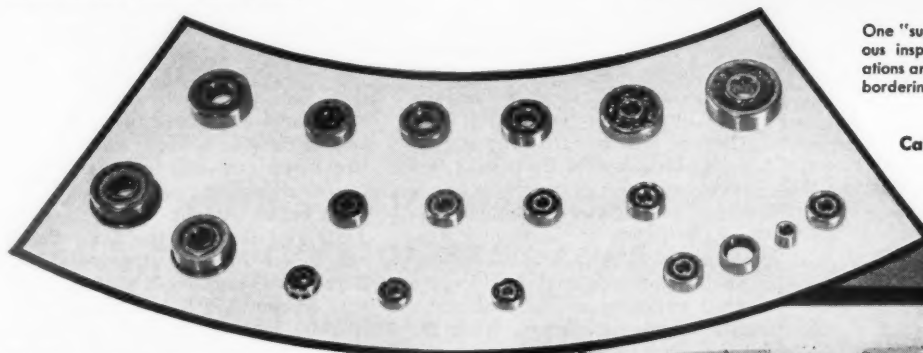
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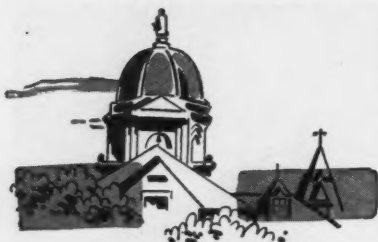
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stage will be controlled through part of its powered and all of its coasting flight.

Next, the third stage will be spun and the second stage separated. When the second stage is clear, the third stage will ignite and be spin-stabilized throughout its burning period. At burn-out, approximately 10 min after launching, the satellite and third stage will have a velocity of approximately 25,000 fps, an altitude of 200–400 miles, and a range of approximately 1500 miles.

Toward the Unknown: To reach its orbit, the satellite must survive vibrations from three individual rocket motors, the shocks of rocket starts, steady state accelerations up to 35 g, aerodynamic heating to 300 F and rotation to 150 rpm. But this, said Baumann, is only part of the story.

In trying to design for orbital environmental conditions, the satellite scientists have had to work in an abyss of unknowns relating to such things as ambient temperatures, meteors, space dust, cosmic rays and x-rays. This raised a number of problems. But of all the unknowns, reported Baumann, temperature seemed to create the biggest problem.

The batteries and transistors to be used can only operate in a comparatively narrow temperature range. The orbit, the time of year, the hour of firing all contribute to the variations in temperature expected.

And, of course, the satellite skin will fluctuate through a wide temperature range. It will become extremely cold when the earth is between the satellite and the sun and very hot when it isn't.

Thermal Switch: One way to control this temperature fluctuation, according to Baumann, would be to use a surface coating and at the same time thermally isolate the internal instrument package.

Another approach would be through a thermal switching arrangement which would operate as follows: When the internal package container reaches a predetermined temperature above that of the outer shell, the thermal switch will close, conduct heat away from the internal package. When the internal temperature drops back within the desired limits, the switch will open. It is also possible to make the switch operate in exactly the opposite fashion, said Baumann, when the outside shell is warm and the inside package cold.

Currently, scientists are conducting a thorough analytical and experimental program to find the best heat balance possible. If their estimates of orbital temperature conditions are extremely far off, the satellite equipment will provide data for a few days instead of the two weeks it was designed for. But even so, said Baumann, this would tell them where they went wrong in their

calculations and thus give the next unit a greater chance.

Finally, he concluded, when the satellite does hit its orbit, it will serve as a reliable laboratory in space which will be instrumental in unlocking some of the secrets long held by this planet and the surrounding space. And sparse as these answers may prove, the indication is that they will more than satisfy Baumann and the other satellite men for the work involved.

In an address at the Power for Progress Luncheon on the final day of the meeting, Maj. Gen. David H. Tulley, commanding general, Engineering Center, Ft. Belvoir, Va., outlined the Army Corps of Engineers role in support of guided missiles.

Noting that the Corps had supported the Nike construction program during the last few years to the tune of some \$300 million, Gen. Tully briefly reviewed the various activities of the Corps in the Army missile program. He noted that the Corps is responsible for buying real estate for Army missile test centers, building housing, handling electrical power and compressed air supply for test installations, and creating the proper missile handling equipment.

On larger missiles, the Corps has the responsibility for the manufacture, transportation and storage of liquid oxygen, transfer of the lox from storage tanks to trailers and from the trailer to the missile itself. Additional responsibilities include surveying, target location, fire fighting, handling of soil erosion and dust prevention programs, and construction of launching facilities, blockhouses and other buildings at missile centers and test ranges.

Packaged Atomic Power: Gen. Tully also discussed the Army Package Power Reactor program at Ft. Belvoir and announced that the first such reactor, APPR-1, with an output of 2000 kw, will be dedicated some time this month.

Athelstan F. Spilhaus, dean, Institute of Technology, University of Minnesota, and a member of the Executive Board of UNESCO, was the featured speaker at the Spring Banquet on the closing day of the meeting. Jet propulsion pioneer Theodore von Kármán, chairman, Advisory Group for Aeronautical Research and Development, NATO, was the speaker at the Human Factors Luncheon on the first day of the meeting.

The ten technical sessions, centering on four subjects—high-speed sleds (see page 422), space sociology, astronautics and propulsive systems—were well attended and produced a number of outstanding papers.

Credit for the highly successful meeting, the first national meeting to be held

JET PROPULSION



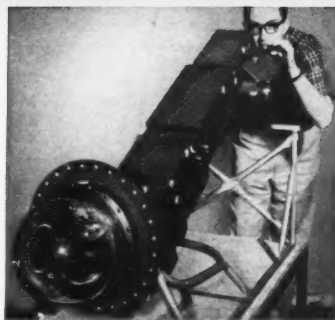
He's getting new basic knowledge on properties of semi-conductors

Here Dr. Rolf K. Mueller determines electrical properties of a semi-conductor specimen having a low angle grain boundary. He and his colleagues in the Electron Physics Laboratory of the Mechanical Division of General Mills grow their own pure specimens with carefully oriented crystal structures (germanium in this case). They then mount specimens very precisely for basic research involving the effect on physical properties of varying angles of junction. Variation of the angle of crystal orientation at the junction (the "grain boundary") has a predictable effect on the electrical reactions of the semi-conductor.

Semi-conductor work is but one facet

of an integrated program in solid state physics. Studies of chemical, mechanical and surface properties of solid crystals and "sputtering" of metals under ion bombardment are among several other areas presently being researched in the Electron Physics Laboratory.

Some of this research is still basic, but it typifies the advanced and creative work we do. In many fields, this "research for tomorrow" is translated regularly into practical applications for industrial and military use today. If you have product or production problems, possibly you can profit from these applications and from our precision production facilities.



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in Washington, belongs largely to the National Capital Section, which did an outstanding job as host and set up an extremely interesting program.

San Francisco Meeting Coming Up in June

THE ARS Semi-Annual Meeting will be held at the St. Francis Hotel in San Francisco, June 10-13, 1957. Meeting Chairman Antoni K. Oppenheim, who is also president of the host Northern California Section, announces that a luncheon, a banquet and a field trip to the NACA's Ames Aeronautical Laboratory will be included.

In addition, Program Chairman Kurt Stehling and the six Technical Commit-

tees have arranged a slate of nine technical sessions—on instrumentation, guidance, combustion, solid rockets, liquid rockets, hypervelocity flight and space flight.

The Sacramento Section will take charge of the luncheon to be held on June 11. Speaker for the luncheon will be Dan Kimball, president of Aerojet-General Corp. and former Secretary of the Navy.

The meeting will be held in conjunction with the Semi-Annual Meeting of ASME at the Sheraton-Palace Hotel. ASME's Aviation Division will hold sessions on aircraft maintenance and aircraft mechanisms there.

The full program for the meeting will be carried in the May issue of JET PROPULSION.



Irwin Hersey



William Chenoweth



Robert C. Toth



Dean Roberts

Hersey, Chenoweth, Toth Join JET PROPULSION Staff; Roberts to Direct ARS Public Relations

IN A move designed to provide more thorough coverage of the rapidly expanding rocket and guided missile industry in its publications and increase member services, the AMERICAN ROCKET SOCIETY last month announced five new staff appointments.

Irwin Hersey has been named Editor-in-Chief and William Chenoweth has been appointed Advertising and Promotion Manager of JET PROPULSION, while Robert C. Toth joins the magazine as News Editor and John Culin as Art Editor.

Dean Roberts has been named to the newly created post of Director of Public Relations for the SOCIETY.

As the first full-time Editor-in-Chief of JET PROPULSION, Mr. Hersey will assume complete editorial responsibility for the publication. Martin Summerfield, Professor of Jet Propulsion and Aeronautical Engineering, Princeton University, and Editor-in-Chief since 1951, will continue on the staff in the new position of Technical Editor.

Prior to joining JET PROPULSION, Mr. Hersey was managing editor of *Motor* for four years. He has been in the publications field since 1940, with experience on consumer newspapers, trade magazines and business publications. He was previously editor-in-chief of the *Government Procurement Weekly Review* and market editor and reporter for *Daily*

News Record. He saw service as an Army intelligence officer in World War II, as well as the Korean War. He is a graduate of the College of the City of New York and did postgraduate work at Columbia University and the University of Michigan.

Mr. Chenoweth has been in the advertising field for over 10 years, with a background in both newspaper and industrial advertising. Before joining JET PROPULSION, he was an account executive with Wheelock Associates, New York City, on the Reaction Motors and Stroukoff Aviation accounts, as well as other industrial accounts. He also served as media director during his two and a half years with the agency. Previously, he was an account executive with the London Advertising Agency for two years and was with *The New York Times* Advertising Dept. for six years. He served in the Army Signal Corps in World War II.

Winner of a Pulitzer Traveling Scholarship in 1955, Mr. Toth comes to his new position from the *Providence Journal-Evening Bulletin*, where he covered general news while handling special science assignments for the past year and a half. A graduate of Washington University of St. Louis with a B.S. in Chemical Engineering, he received his M.S. in Journalism at Columbia University in 1955. He was previously a chemical en-

JET PROPULSION



Lightweight! But magnesium can really take punishment

Magnesium is the world's lightest structural metal. It weighs only 23% as much as steel, 20% as much as yellow brass and 65% as much as aluminum. But magnesium is strong, too. How strong? Look at a few of its uses in the aircraft industry, for example:

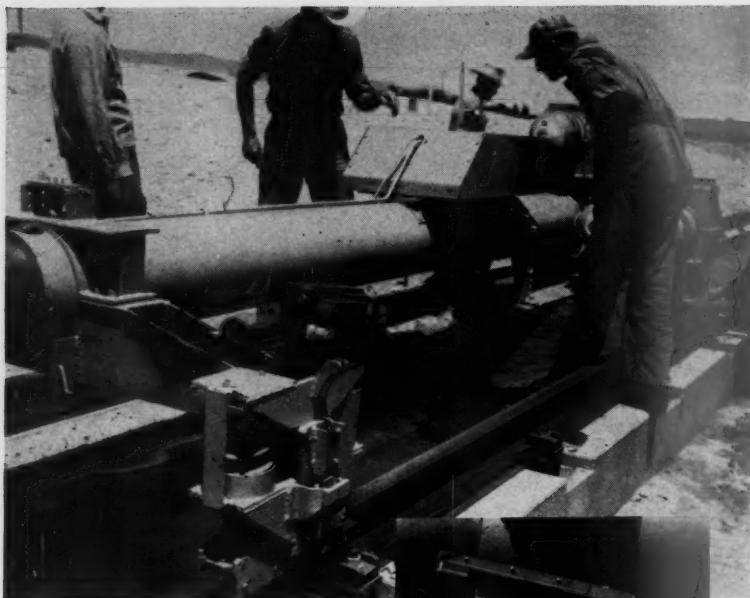
The magnesium wheel in the picture above has to be light, but it also has to withstand tremendous shock when the plane touches down. In another application, the entire weight of a two-ton helicopter is suspended from a magnesium rotor. In large cargo planes magnesium floor members support heavy weights in flight.

Magnesium was selected because it has the necessary lightness, strength, rigidity, durability and other desirable properties. It's the *combination* of light weight and strength that makes magnesium the choice for countless applications throughout industry.

What do these facts mean in terms of your products, parts or equipment? They mean that magnesium can do an equal or better structural job at a substantial savings in weight. For more information, contact the nearest Dow sales office or write to us. THE DOW CHEMICAL COMPANY, Midland, Michigan, Magnesium Department MA 1401F.

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Air Force crew readies sled equipment prior to acceleration tests. Inset: Fairchild Motion Analysis Camera was focused on forward shoe. With lens pointing forward, it took clear, steady pictures at 120g's initial, 45g's average state. Photo courtesy Coleman Engineering Company, Inc.

Steady pictures at 120g's

Fairchild high-speed camera records shoe action in rocket sled test

If you have ever analyzed high-speed phenomena, you can appreciate this Fairchild Motion Analysis Camera's performance in a recent Air Force rocket sled test. With lens pointing forward, the camera caught the action of the sled shoe without film jump or flutter—in spite of the high acceleration, vibration and shock.

Designed for airborne and vehicular applications, the Model HS100 has consistently taken good pictures under the following environmental conditions:

- Shock: 165g's repeatedly
- Vibration: 20g's at 10 and 50 cycles
10g's at 100, 200 and 500 cycles
- Temperature: -65°F to 194°F (without heaters)

Only 11 lbs. in weight, the Model HS100 has motor ranges of 16-100, 32-250, 80-2000, 700-2400 pictures per second with stop-start operation at speeds up to 450 pps. Lenses range from 3.7mm to 152mm.

Like to know more about the Fairchild HS100 and high speed photography? Mail the coupon today.

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gineer at Picatinny Arsenal and assistant editor of *Rubber World*.

Mr. Culin has been art director of *Gourmet* magazine for the last year and a half. Previously, he was with Fawcett Publications for more than four years, serving as associate artist for *True* and art director for *Television Life*. He attended Syracuse University and Pratt Institute.

As ARS Director of Public Relations, Mr. Roberts will be responsible primarily for membership services. A graduate of William and Mary College, he has been on the public relations staff of General Motors Corp. for the past three years.

ARS Headquarters In New Location

AMERICAN ROCKET SOCIETY national headquarters moved last month to new and larger quarters in the same building at 500 Fifth Ave. in New York City. Headquarters offices are now in Room 833, while JET PROPULSION editorial offices are in Room 840. The new phone number for both offices is Pennsylvania 6-6845.

People in the News

APPOINTMENTS

• **C. A. Gongwer**, manager of the Underwater Engine Div., Aerojet-General Corp., co-inventor of the MiniSub and originator of Alclo propellant, has been appointed to the company's recently established Large Solid Propellant Rocket Advisory Committee.

• **Orrin C. Bowers** has been named chief engineer of BJ Electronics, Borg-Warner Corp. He was previously projects manager of the Electronic Instrumentation Div., Ramo-Wooldridge Co.

• **W. R. Clay** has been appointed director of the Engineering Laboratory of the newly formed Aircraft Div., Rheem Mfg. Co. He moves up from assistant manager of the Research and Development Laboratory.

• **Irving Forston** has been named chief engineer, **Frederick R. Hickerson** senior project engineer and **John J. Canavan** head of the Rocket Test Div., Engineering Dept., U. S. Naval Air Rocket Test Station, Dover, N. J.



Gongwer



Bowers

JET PROPULSION

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• **Chester M. McCloskey** has been appointed executive director of the Industrial Associates of the California Institute of Technology. Dr. McCloskey has been chief scientist at the Office of Naval Research in Pasadena since 1955.

• **Granger Associates** has named **William E. Ayer** vice-president and director of engineering. Dr. Ayer has been a research associate with Stanford University's Electronics Laboratories for the past six years.

• **C. M. Martenson** has been elected vice-president and general manager of Bell Aircraft and Hydraulic Research and Mfg. Co., a subsidiary of Bell Aircraft. He has been with the firm for the past eight years.

• **E. V. Space** will fill the newly created position of manager, Equipment and Production Development, RCA Semiconductor Div. He was formerly manufacturing manager of the division.

• **Minneapolis Honeywell Regulator Co.** has named **Boyd E. McKnight** senior applications engineer of its Davies Laboratories Div. Prior to joining Davies, he was engineering sales manager for Koessler Sales Co., Los Angeles.

• **Frank Beardsley** has been named staff engineer for the Automatic Controls Div., Clary Corp. He was chief engineer at Summers Gyroscope Co. for three years before joining Clary.

• **James F. Healey** has been appointed chief of plans and programs for the Aeronautical Div., Minneapolis-Honeywell Regulator Co. Before joining the company, he was head of Bell Aircraft's aeronautical automatic control facility in Cleveland.

• **Bendix Aviation Corp.** has named **R. E. Whiffen** and **J. P. Field** to key posts in the missiles section of its products division. Whiffen will be Mishiwaka, Ind., plant manager, in charge of manufacturing activities of the Talos missile, while Field will be quality manager of the section and responsible for all missile testing and inspection.

• **J. W. Goslee** has been named West Coast service engineer by Chandler-Evans (Ceco) Div., Pratt-Whitney Co.



Alfred J. Eggers

• **Panellit, Inc.**, has appointed **G. A. Walley** chief engineer of its newly opened Alhambra, Calif., manufacturing facilities. He was formerly a senior project engineer for the company.

HONORS

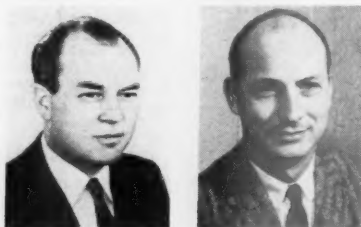
• **Rudolf H. Thielemann**, chairman of Stanford Research Institute's Metallurgy Dept., has been reappointed chairman of the subcommittee on powerplant materials and a member of the committee on aircraft powerplants, National Advisory Committee for Aeronautics.

• **Alfred J. Eggers**, aeronautical research scientist at the Ames Aeronautical Laboratory, Moffett Field, Calif., has been named one of the 10 outstanding young men in the Federal government. Dr. Eggers, 34, cited for his work in the field of atmospheric re-entry, flight problems at hypersonic speeds, and development of a hypersonic wind tunnel, received an Arthur S. Flemming award along with nine other government employees.

***Astronautica Acta* Now Available through ARS**

Astronautica Acta, the official journal of the International Astronautical Federation, may now be obtained by AMERICAN ROCKET SOCIETY members at reduced rates by subscribing through the SOCIETY. Such member subscriptions will cost only \$6.88 a year, compared with the regular subscription price of \$8.60.

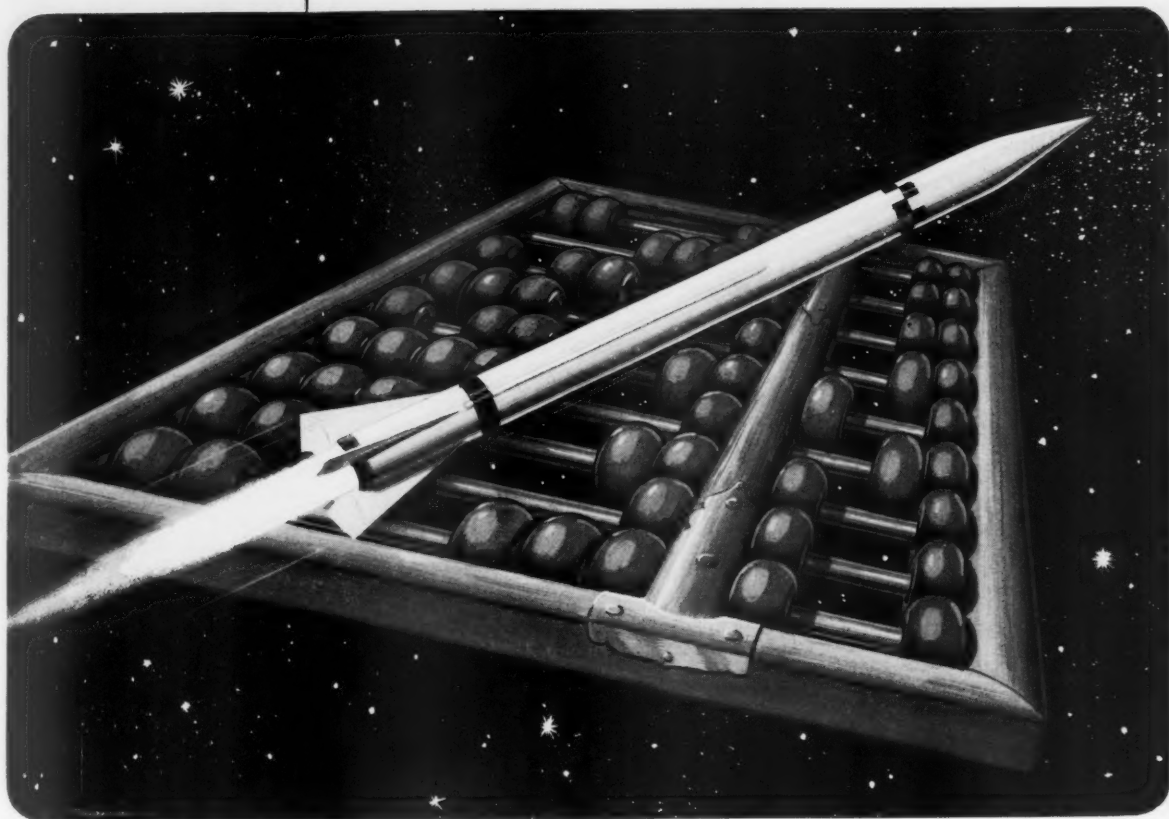
The magazine, a quarterly published by Springer-Verlag in Vienna, is being enlarged this year and will henceforth contain 256 pages annually at no increase in cost. The increase in the number of pages, making the magazine one-third again as large as it was originally intended to be, has been decided upon to meet the growing number of requests for publication of astronautical works coming in from all over the world.



McKnight

Beardsley

IMPORTANT ACHIEVEMENTS AT JPL



Computers for Missile Guidance

The Jet Propulsion Laboratory is a stable research and development center located north of Pasadena in the foothills of the San Gabriel mountains. Covering an 80 acre area and employing 1700 people, it is close to attractive residential areas.

The Laboratory is staffed by the California Institute of Technology and develops its many projects in basic research under contract with the U.S. Government.

Opportunities open to qualified engineers of U.S. citizenship. Inquiries now invited.

The abacus is a very ancient and useful computing device in the hands of a person versed in its use. However, the requirements for speed and accuracy in computing the functions necessary for modern missile guidance have obsoleted all man-operated devices, creating a need for computing systems previously considered impossible.

The Jet Propulsion Laboratory pioneered in the application of analog computing techniques to missile guidance systems and, to maintain its leadership in this field, constantly searches for new techniques that will make optimum use of magnetics, transistors and other modern computing components.

The successful application of these techniques to missile systems under development requires designs that will perform properly under the adverse environments

found in today's guided missile. A degree of accuracy and extreme reliability, previously thought possible only under controlled laboratory conditions, is now a reality because of improved instrumentation techniques and development of highly accurate instrumentation equipment. This has been successfully applied to development of special purpose equipment for missile guidance.

The JPL guidance computer group, now engaged in research and development work encompassing electronic, mechanical, electromechanical and servo computing systems and their application to missile guidance and control, now offers attractive opportunities for truly creative engineers interested in advancing the state of computer art.

Send your resume today for immediate consideration.

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Provide preliminary design engineering on potential new products, major improvements in growth versions of current engine models, with particular reference to the turbine. Participate in the coordination and integration of the turbine with all other engine systems, components and parts.

REQUIRED: at least 6 years in the design of turbines for jet engines or related experience.

Advanced degree desirable. Salaries commensurate with the responsible nature of the positions.

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Shown (l to r) in photograph at top, taken at annual dinner meeting of the Alabama Section, are W. A. Davis, Jr., 1956 secretary; D. H. Newby, newly elected vice-president; C. E. Fitton, Jr., the new president; C. D. Swanson, 1956 president; and G. A. Devel, the new treasurer. In photo above (l to r) are Swanson, Major Gen. John B. Medaris, Fred Singer, Fitton, and Wernher von Braun.

Sections

Alabama: Fred S. Singer, principal speaker at the annual meeting, got himself involved in a bet on the time scale for travel to the moon. During the question and answer session that followed Dr. Singer's address on "Education for the Space Age," he was asked when the moon would be reached by an earth-launched vehicle and avoided giving an answer. Hal Ritchey arose from the audience, offered to bet Dr. Singer (the stake: one beer) that the feat would be accomplished within five years. Maj. Gen. J. B. Medaris, Army Ballistic Missile Agency commanding general, a guest at the meeting; Wernher von Braun, who introduced Dr. Singer; and former Section President Conrad Swanson were named to a committee to determine the winner of the bet.

New officers of the Section are C. E. Fitton, Jr., president; D. H. Newby, vice-president; and G. A. Devel, treasurer.

Antelope Valley: Under the leadership of R. A. Schmidt, president; R. A. Clark, vice-president; Pete Nicolay, secretary; and A. I. Hoffman, treasurer, the section has worked out a program for the remainder of the year and is now planning a first anniversary meeting on May 9.

The Section had its largest open meeting to date recently, when over 130 members and guests turned out to hear Dieter K. Huzel of Rocketdyne, who was at Peenemunde during World War II, present a first-hand account of the development of the V-2 through slides and movies. In front of the V-2 engine on display at the meeting are (l to r) Section President R. A. Schmidt; Richard Gompertz, board member; Walter Detjen, membership committee chair-

man; vice-president David Clark; Dieter Huzel; D. R. Bellman, board member; and secretary Pete Nicolay.



At the following meeting, John Gustavson, Convair-Astronautics, presented a talk illustrated with slides on "Space Flight—Today and Tomorrow."

Arizona: Recent meetings of the Section have been enlivened by the showing of educational movies. During the past few months, members have seen films on a hypothetical excursion into space, the number of stars in space, and two films on the Falcon missile.



Central Texas: Lt. Col. John P. Stapp, principal speaker at a combined meeting of the Section with personnel from the Rocket Fuels Div., Phillips Petroleum Co., is shown above at the meeting in a discussion with (l to r) I. L. Coffman, Phillips; E. F. Fiock, newly elected president of the



B. Ellis (center), head of the Propulsion Department, discusses methods of accurate thrust termination for a ballistic rocket with Dr. Howard M. Kindsvater (left), propulsion staff engineer, and André P. Bignon, propulsion research specialist.

PROPULSION ACCURACY—*a major missile problem*

Controlling power action is but one of the major problems facing propulsion engineers and scientists. Important advances in this and related areas of propulsion are necessary to missile systems now in development.

Because of the growing complexity of problems now being approached, Propulsion Engineers find their field offers virtually limitless scope for accomplishment. The ability to perform frontier work is essential.

Engineers and scientists possessing a high order of ability and experience in propulsion and related fields will be interested in new positions now at Lockheed Missile Systems Division's Sunnyvale and Van Nuys Engineering Centers. Inquiries are invited.

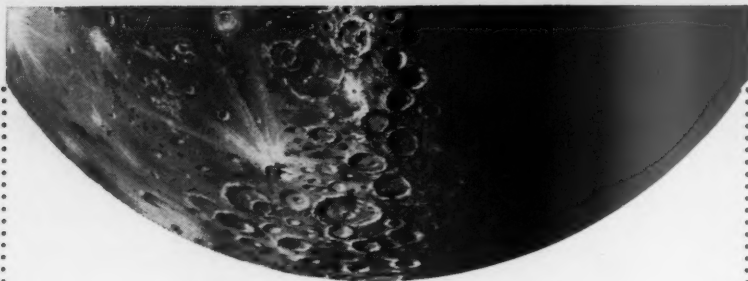
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MISSILE SYSTEMS DIVISION

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To that rare breed of men who can
"see" the shape of things to come:

We can use your ideas in Large Rocket Engineering

We have a small but heavyweight group here at Rocketdyne known as the Preliminary Analysis & Design Section.

These are our idea men. It's their job to see the Big Picture... to approach outer-space projects without earthbound prejudice... to anticipate problems and sense the likeliest ways to solve them. They are qualified experts in a broad range of fields. Some have extraordinary imaginations; others are brilliant analysts; but all share the ability to hit the highlights without becoming enmeshed in the details. In short, they are scientific skirmishers who scout each new challenge—then summon research and development specialists to meet it.

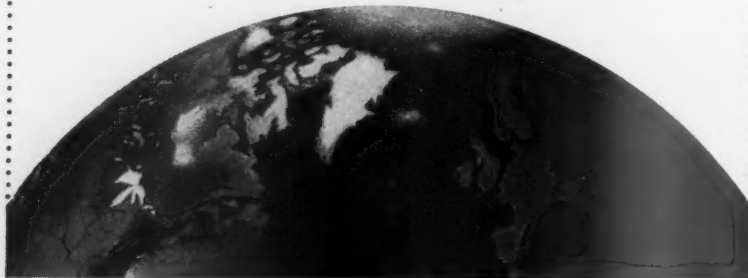
If this sounds like *your* kind of group, you may be the very man we're seeking for one of the several jobs now available. We can't describe them in detail here, but they include *Controls, New Concepts* (nuclear and ion applications), *Preliminary Design, Fluid Mechanics, Heat Transfer, Engine & Missile Systems*, and *Military Operations Analysis*.

We can use men with advanced degrees and solid experience in control systems and power-plant design. If you are a young engineer or physicist with an M.S. or Ph.D. and an analytical turn of mind, we can offer on-the-job training in many pioneering fields where experience is practically nonexistent.

Please tell us about yourself—what you've done... what you'd like to do. Write: A. W. Jamieson, Rocketdyne Engineering Personnel Dept. R-4, 6633 Canoga Ave., Canoga Park, California.

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A DIVISION OF NORTH AMERICAN AVIATION, INC.

BUILDERS OF POWER FOR OUTER SPACE



Section; and M. F. Kraettli, Phillips. Col. Stapp illustrated the discussion of his work with motion pictures and slides.

New officers of the Section (below, 1 to r) are E. F. Fiock, president; J. O. Grantham, secretary; A. C. Keathley, treasurer; and A. E. Inman, vice-president and program chairman.



At its last meeting, the group heard a talk by R. C. Lea, Glenn L. Martin Co., on the Earth Satellite program. The Section is now trying to obtain the necessary equipment for acting as an observation group for the IGY satellite.

A month earlier, a joint meeting was held with the North Texas Section in which the group made a tour of AF Plant 66 in McGregor, Tex.

Chicago: John Kre, Jr., has been elected president; Stephen J. Fraenkel, vice-president; Richard W. Ziemer, secretary; and George Herman, treasurer, for terms ending next May—following an amendment to the bylaws changing the Section fiscal year, which will henceforth start June 1 and end May 31 of the following year. At the same meeting, Charles R. Heising of General Electric Co. discussed the operation and application of the turbojet simulator for the development of engine accessories and controls under simulated altitude and dynamic flight conditions. The use of the simulator for rocket engine controls was also indicated.

Columbus: Darrell C. Romick, aerophysicist, Goodyear Aircraft Corp., addressed a meeting of the Section which attracted a record attendance of 97 members and guests. Mr. Romick's topic was "The Dawn of the Age of Space Travel," and the lecture was highlighted by the showing of a number of color slides. An interview with Mr. Romick on a local TV station produced a number of phone calls for additional information about the meeting. Last month, the group visited the Perkins Observatory.

Detroit: The University of Michigan Student Section acted as host for a recent meeting of the Detroit Section. Jack Irving of Ramo-Woolbridge Corp., the guest speaker, discussed the demands space flight will make on the arts of propulsion and guidance. C. W. Williams of Chrysler Missile is president of the Section; L. Lawrence of Chrysler Missile, vice-

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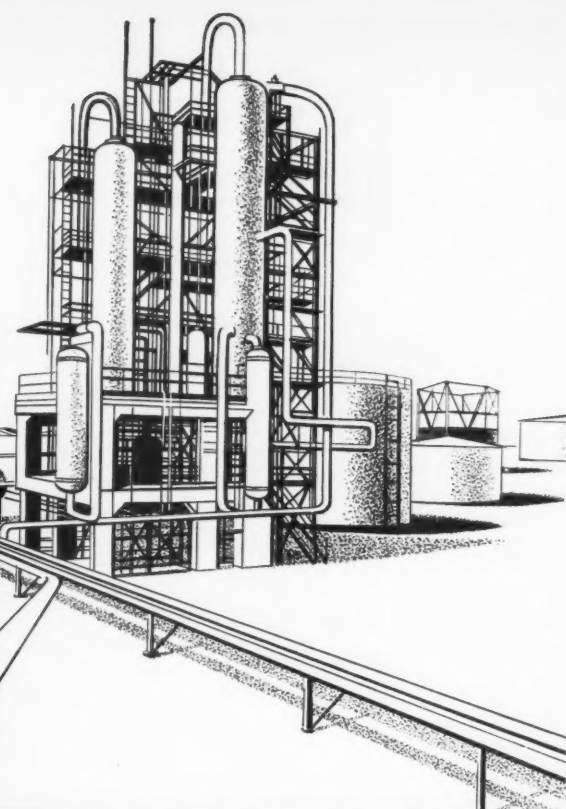
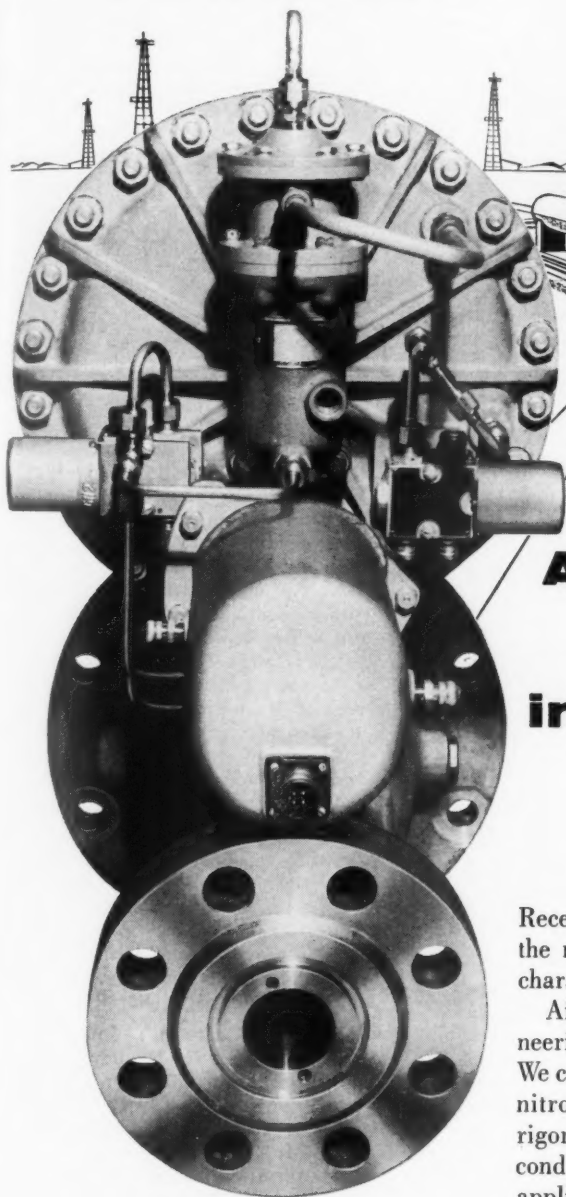
Temp. range: +400° F. to -300° F.

Size: inlet dia. 2" — outlet dia. 8" — length 18"

Downstream pressure regulated up to 300 psig

Pressure regulation maintained within 1% of setting

Downstream pressure programmed with timing motor



AiResearch valves solve special industrial problems

Petroleum Industry Applications

Chemical Industry Applications

Rocketry Applications

Nuclear Energy Applications

Recent scientific and engineering advances have multiplied the needs for valves and controls with critical operating characteristics.

AiResearch has fifteen years of experience in the engineering and fabrication of specialized valves of all types. We can solve problems which include the handling of liquid nitrogen, liquid oxygen and pressurized helium under rigorous extremes of heat, cold and other environmental conditions. The valve illustrated, developed for a rocketry application, is an example of our capabilities in this field.

If you have a problem involving specialized valves, we invite you to contact us.



AiResearch Industrial Division

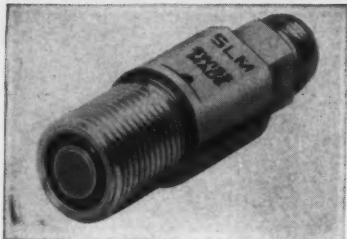
9225 South Aviation Blvd., Los Angeles 45, California

DESIGNERS AND MANUFACTURERS OF TURBOCHARGERS AND SPECIALIZED INDUSTRIAL PRODUCTS

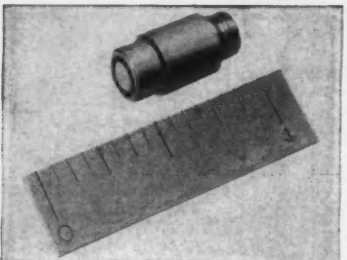
APRIL 1957

457

NEW PRODUCT NEWS



Model PZ-14



Model PZ-6

Kistler SLM Transducers measure combustion, detonation, hydraulic and pneumatic pressures precisely

Featuring extreme ruggedness, high sensitivity and fast response, the precision, Swiss-made SLM Pressure Transducers permit direct measurements of pressure and rate of pressure changes.

Providing continuous operation at steady temperatures up to 600° F, with intermittent gas temperatures on the diaphragm to above 3000° F, they give faithful response to fast or slow pressure variations in shock tubes, gun tubes, rocket motors, rocket sleds, aerodynamic models, gas turbines, diesel and gasoline engines, compressors, fuel pumps, hydraulic and pneumatic control systems.

Calibration is constant and practically independent of temperature. This is the only commercially available crystal type instrument that can be calibrated by conventional static methods.

Pressure changes generating an electrical charge in the pickup are measured by an electrostatic type Kistler amplifier and displayed on an oscilloscope. Voltage signals are about 1000 times higher than from a typical strain gage or inductive type instrument. The standard Model PZ-14 Transducer covers all pressure ranges from 0.1 psi to 3000 psi and measures full vacuum. A Kistler pickup adaptor extends this range to 30,000 psi. Response time is 15 microseconds, resolution .01 psi with linearity and repeatability better than 1% of the pressure being measured. Designed for relatively "hard-to-get-at" locations, the Sub-Miniature Model PZ-6 Transducer achieves response times to one microsecond. A new electrostatic feedback amplifier is available for use with this type pickup.

The SLM Pressure Pickup, combined with special low-noise cables and a Kistler Piezo-Calibrator-Amplifier (required to couple pickups to oscilloscopes or recorders) constitutes the Kistler SLM Pressure Indicator. For complete information, request Bulletins PI-114, PZ-14 and PZ-6.

Kistler Instrument Corp., Dept. JP
15 Webster St., North Tonawanda, N. Y.

president; C. Tait, Wyandotte Chemicals, treasurer; and L. B. Forman, Chrysler Missile, secretary.

Holloman: Rudolf Hermann, professor of aeronautical engineering at the University of Minnesota and project scientist at the university's Rosemont Aeronautical Laboratories, was the guest of honor and principal speaker at the February Charter meeting, which celebrated the achievement of full Section status by the Holloman group in the ARS.

Some 85 persons who attended the January dinner meeting heard Lt. Col. Louis W. Triblett, deputy director, Ballistic Missile Testing, at Holloman, discuss "The Philosophy of R&D Testing."

Maryland: Raymond Colter of the University of Maryland Physics Dept. discussed the Terrapin rocket and its development at a recent meeting of the Section. Also featured on the same program was a movie entitled "American Engineer," which pointed up significant engineering developments across the nation.

New Mexico-West Texas: An address by Lee Trafton, assistant chief of management services, Comptroller's Office, White Sands Proving Ground, on the subject of "Manpower" highlighted the February meeting. Mr. Trafton discussed the subject from the psychological, physiological and economic viewpoints, with special emphasis on the demand for engineers and technicians in the field of rockets and guided missiles. A lively question and answer period followed the formal part of the program.

North Texas: The Section is co-sponsoring a Science Explorer Post of the Boy Scouts of America in Ft. Worth. About 15 young men and their parents turned out for the recent organizational meeting of the post (see photo). Jimmie B. Haden, Section program chairman, is the post advisor, while George Craig, president, Roger Crippliver, publicity chairman, and Charles Crabtree, secretary, are members of the post technical committee. Full utilization of industrial laboratories, workshops, exhibits and other resources is contemplated, and post members will assist in choosing scientific themes and projects for the group.



New York: Leo Steg, manager, Aero Sciences Laboratory, Special Defense Projects Dept., General Electric Co., was the guest speaker at the Section's March meeting. Dr. Steg discussed the origins and present understanding of the major problems of hypersonics, some of the methods used for simulation of hypersonic environment and present understanding of the nature of simulation.

Membership in the Polytechnic Institute of Brooklyn Student Chapter has grown to 45. The Chapter is now issuing a publication called *Rocket News*.



Sacramento: Newly elected officers are D. M. Tenenbaum, president; C. M. Beighley, vice-president; W. H. Fenton, secretary; and H. L. Coplen, treasurer. Photo above taken at recent meeting shows (r to l) Kurt Stehling, ARS national program chairman, who spoke on plans for the ARS Spring Meeting in Washington; Burton J. Moyer, senior staff physicist at the University of California Radiation Laboratory and consultant to Aerojet-General Nucleonics, principal speaker at the meeting; President Tenenbaum, Secretary Fenton, Mrs. Fenton and G. S. James.

San Diego: Reminding his audience that it would take 10 years at the speed of light for a space ship to reach the nearest star, George Gamow, noted theoretical physicist and author, suggested last January 6 that freezing of the travelers (with automatic defrosting before arrival) might be one way of killing time.

Southern California: John Crum, project engineer for the development of propellant utilization systems, Ramo-Wooldridge Corp., was the principal speaker at the March meeting. Mr. Crum described the propellant utilization problem as related to long-range liquid propellant rockets

Getting Talos Off to a Good Start

For its initial flight, the XX*-ton Talos ram-jet missile is pushed skyward by a powerful booster rocket. In a split second from launching, internal pressures are up to XXXX* psi . . . nozzle temperatures to XXXX* F. To design and produce a unit to endure such sudden torture called for an unusual combination of specialized engineering and fabricating skills. A major responsibility for the Talos rocket case was assigned to The M. W. Kellogg Company

Since 1951, M. W. Kellogg has been closely associated with the development and production of propulsion units for a wide range of missiles. Kellogg's most recent contribution is the development of reinforced plastic for rocket cases, using a unique filament winding method which produces structures of unparalleled accuracy and light weight.

DESIGN
ENGINEERING
DEVELOPMENT
PRODUCTION

*Actual figures classified

FABRICATED PRODUCTS DIVISION

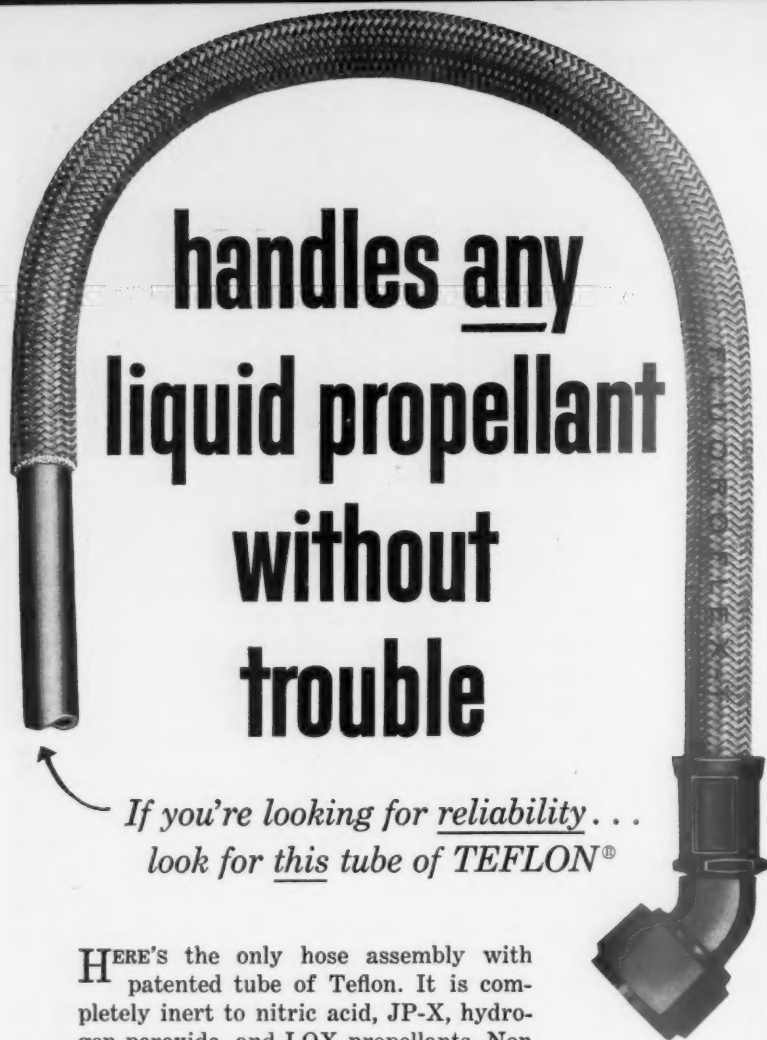
THE M. W. KELLOGG COMPANY

711 THIRD AVENUE, NEW YORK 17, N. Y.

A SUBSIDIARY OF PULLMAN INCORPORATED

The Canadian Kellogg Company, Limited, Toronto • Kellogg International Corporation, London
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Kellogg Pan American Corporation, New York • Societe Kellogg, Paris





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look for this tube of TEFLON®

HERE'S the only hose assembly with patented tube of Teflon. It is completely inert to nitric acid, JP-X, hydrogen peroxide, and LOX propellants. Non aging, it has indefinite storage life.

Fluoroflex®-T (Teflon) hose assemblies are rated for -65°F to +450°F continuous operation. They incorporate stainless steel fittings, and are also available in combination with bent tube configurations to meet your most critical specific requirements. For missile launching installations, Fluoroflex-T assemblies can be equipped with external spring guards for optimum protection against severe physical abuse.

Resistoflex is the first and foremost hose assembly manufacturer extruding its own Teflon tubing and thus fully controls the quality of the entire hose assembly. Send for Bulletin FH-2.

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20th year of service to industry

RESISTOFLEX

CORPORATION • Roseland, N. J. • Western Plant: Burbank, Calif.
Southwestern Plant: Dallas, Tex.

and outlined possible means of alleviating the problem.

Project Vanguard was the subject for Aerojet-General Corp.'s Wayne D. Stinnett who was guest speaker at the January meeting in Los Angeles. Mr. Stinnett prefaced his discussion of the Vanguard project with background material on upper atmosphere research.

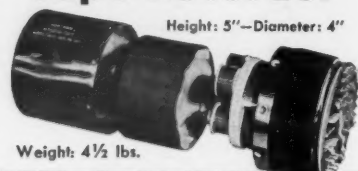
Southern Ohio: Jerome Berman of Cincinnati and James J. Harford, ARS Executive Secretary, were the guest speakers at the February meeting. Dr. Berman spoke on some early American rocket experiments, while Mr. Harford discussed past and present activities of the ARS.

Twin Cities: Martin Summerfield, technical editor of JET PROPULSION and jet propulsion professor at Princeton University, was the featured speaker at the January 10 meeting. His subject: "Problems of Propellant and Trajectory Selection for Launching an Earth Satellite."

ARS Meetings Calendar

June 10-13: ARS Semi-Annual Meeting, Hotel St. Francis, San Francisco.
Aug. 25-28: ARS-Northwestern Technological Institute Gas Dynamics Symposium, Northwestern University, Evanston, Ill.
Dec. 2-6: ARS Annual Meeting, New York.

NORTHAM Miniature Magnetic Tape Recorder



Eight channels of information can be applied simultaneously to a 1/2-inch tape in the Model MR-1 Recorder (illustrated). This self-contained unit includes transistor timing oscillator and battery power source and operates under axial accelerations up to 500 g. A pre-record carrier system permits direct coupling with D.C. devices such as thermocouples and strain gauge transducers.

MODEL MR-1 SPECIFICATIONS:

Accuracy: ±5% full scale
Sensitivity: 28 millivolts D.C. full scale
across 40 ohms impedance
Frequency Bandwidth: 0-250 cps
Timing: 1000 cps transistor oscillator
Running Time: 45 seconds
Applications: Running time, number of channels and recording characteristics are adaptable to meet requirements of applications—including rocket and aircraft flight testing, oil well logging and atmospheric studies.

WRITE FOR BULLETIN NO. . . . JP-104

NORTHAM PRODUCTS INCLUDE . . .

Transducers for pressure, acceleration and displacement measurement and auxiliary electronic equipment for complete systems.

NORTH AMERICAN INSTRUMENTS, INC.
2420 North Lake Avenue • Altadena, Calif.

JET PROPULSION

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can be as big as
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Since early in World War II, Douglas has been engaged in missile projects of prime importance. New engineering teams are constantly being formed for research, design, development and production. Engineers advance rapidly as Douglas expands its leadership in this challenging field.

You are stimulated to accelerate your career by the importance of each assignment ... by the help of your associates who are recognized experts in missile work ... by the vastness of opportunity for engineers in this company that is run by engineers.

There is no more promising future than that which awaits you in the Douglas Missiles Divisions.

THOR—an intermediate range ballistics missile now under development—has top priority in our country's program for national defense.

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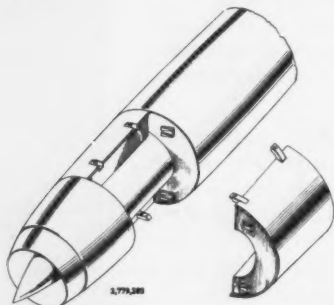
George F. McLaughlin, Contributor

Six component balance for wind tunnels (2,768,526). George S. Trimble, Jr., Lewis G. Cooper, and Werner F. Hess, Middle River, Md., assignors to The Glenn L. Martin Co.

Strain gage balance comprising cages and bulkheads spaced apart and connected by legs. The balance offers low resistance to relative movement when desired moment components are applied, and high resistance when undesired moments are applied.

Combustion engine control apparatus (2,776,536). Alex B. Chudyk, St. Louis Park, Minn., assignor to Minneapolis-Honeywell Regulator Co.

Automatic control of fuel flow and gas flow to maintain a selected engine speed. Temperature responsive means maintains proportional temperature control of the engine.



Warhead structural and locating attachment (2,779,282). Zanville M. Raffel, Rockville, Md., assignor to the U. S. Navy.

Missile having a plurality of sections, including a warhead, divided into longitudinal portions. Warhead parts are attached to one of the missile parts by cleats which mate with cleats on the warhead.

Nozzle with variable discharge orifice (2,779,157). Jack M. Palmer, Chula Vista, Calif., assignor to Rohr Aircraft Co.

Spherically shaped rigid subsections with curved overlapping edged portions. An actuating member moves the downstream ends of the subsections to cause a reduction of the nozzle area.

Liquid hydrocarbon rocket propellant (2,778,188). Don R. Carmody and Alex Zletz, Park Forest, Ill., assignors to Standard Oil Co. (of Indiana).

Hypergolic fuel derived from the pyrolysis of a hydrocarbon selected from ethane, propane, butane, propylene, butylene, naphthas and gas oils, and a nitric acid oxidizer containing not more than 5 weight per cent of nonacidic materials.

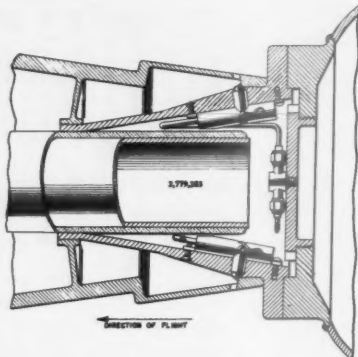
Variable area nozzle for jet engines (2,778,190). Walter R. Bush, Huntington, N. Y., assignor to Republic Aviation Corp.

The effective area of the exit orifice is varied by a nozzle composed of slidably-mounted sections moved in unison laterally with respect to each other.

Supersonic piloted airplane with adjustable nose (2,778,586). Gilbert A. Nyerges and Maurice F. Muzzy, Seattle, Wash., assignors to Boeing Airplane Co.

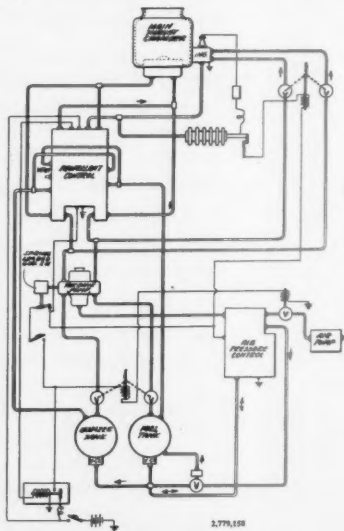
The longitudinal axes of the fuselage

nose section containing the pilot's station, and the fuselage structure, are aligned in high speed flight position. The pilot's station is capable of being lowered relative to the longitudinal axis of the fuselage during low speed flight in order to permit greater vision through the forward windows.



Connector for securing initiator rocket to an aerial vehicle (2,779,283). John E. Baughman, West Hyattsville, Md., assignor to the U. S. Navy.

Means operable by gases generated upon ignition of a booster rocket for releasing a latch connecting the booster to a tail section.



Control for non-hypergolic liquid propellant rocket engines (2,779,158). Richard Thomas Dungan, Clayton, Ohio.

Balanced valves individually control delivery rate of fuel and oxidizer to the thrust chamber, the rate being proportional to chamber pressure.

Lightweight cradle rocket launcher mount (2,779,244). Stephen A. Stam, Glendale, Calif., assignor to the U. S. Army.

Means for manually turning a continuous shaft mounted on a vertical axis, and for affixing a rocket launcher in a cradle for movement as a unit with the shaft.

Ambient pressure responsive control for fuel oxidizer and nozzle exhaust area of reaction motors (2,780,914). Elliot Ring, Schenectady, N. Y., assignor to General Electric Co.

Control of the flow of fuel and oxidizer. A decrease in the cross-sectional area of the nozzle throat is accompanied by a corresponding decrease in the feed rate of the driving fluids.

Fuel distribution system for jet engine and afterburner (2,780,915). H. Peter Karen, San Diego, Calif., assignor to Solar Aircraft Co.

Selector for alternately permitting and preventing fuel flow to pipes mounted at predetermined positions upstream and downstream from the turbine. Fuel is selectively fed to the pipes to control combustion and assure complete and stable combustion within the duct for maximum efficiency.

Pilot burner for jet engines (2,780,916). Whitney Collins, Detroit, Mich., assignor to Continental Aviation & Engineering Corp.

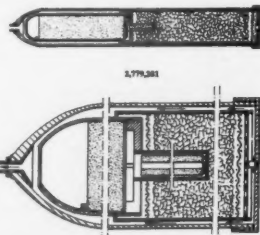
Metered quantities of fuel are injected into the slower moving air in the pilot burner. This provides a combustible mixture of optimum fuel-air ratio regardless of conditions in the main combustion pipe.

Rocket propellant charge and liner therefor (2,780,996). Robert L. Hirsch, Clyde F. Miller and Anthony Bellin, Pasadena, Calif., assignors to Aerojet-General Corp.

Liner for a thermosetting alkyd-vinyl resin inorganic perchlorate type of charge. It comprises a mixture of polyamide resins composed of the products of ethylene diamine with an acid selected from the group consisting of linoleic and linolenic acids and a resin comprising products of polycarboxylic acid and polyhydric alcohol.

Flying aircraft carrier (2,780,422). Melvin R. Maglio, Jr., Suisun, Calif.

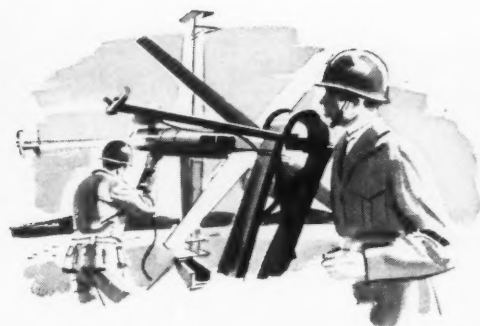
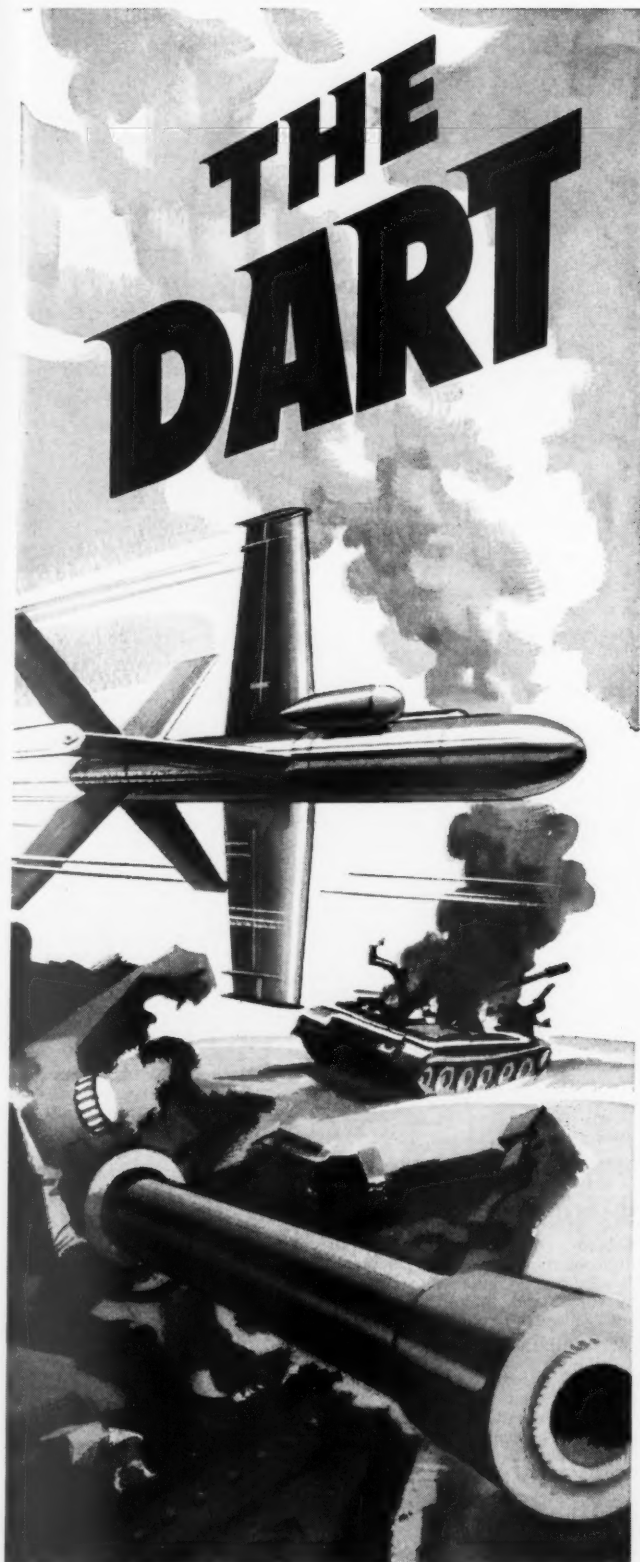
Airplane carrying in its hollow wing a smaller airplane with folding wings and a jet propulsion powerplant. A downwardly extensible launching mechanism on the carrier is releasably engaged with the fuselage of the smaller airplane.



Gas generator (2,779,281). Pierre Maurice and Paul Tavernier, Vanjourn, France, assignors to the French State.

Method of producing gases for injecting liquid into a rocket, for feeding turbines, starting turbine machines, for catapulting, etc. Explosive material fills one end of a casing and a porous support resists the action of the gases filling the other end. An outlet pipe opening into the casing beyond the support collects the gases which produce a stream of compressed gases at temperatures up to 2000 C.

EDITORS NOTE: Patents listed above were selected from the Official Gazette of the U. S. Patent Office. Printed copies of Patents may be obtained from the Commissioner of Patents, Washington 25, D. C., at a cost of 25 cents each; design patents, 10 cents.



Rocket-propelled SURFACE MISSILE gives wings to ground combat

The fast and powerful Dart is a rocket-propelled surface-to-surface missile designed for Army Ordnance by the Aerophysics Development Corporation, a subsidiary of Curtiss-Wright.

While its design and performance are classified, the Dart has been described as a simple but effective anti-tank missile—a single hit from which would probably destroy a heavily armored tank. The five-foot long, highly maneuverable missile has a smokeless-propellant rocket motor.

The Dart represents one of the Army's most advanced ground combat weapons. Another development in the Curtiss-Wright propulsion family, it is typical of Curtiss-Wright's leadership in power to preserve peace.



New Equipment and Processes

Equipment

Electrical, Electronic

High-Temp Capacitor. Teflon dielectric performs to 200 C; ratings are from 0.001 to 2 mfd. Research Laboratories, 49-53 Edison Place, Newark, N. J.



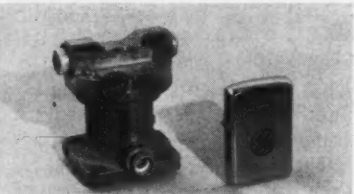
Beacon for Tracking Missiles. AN/DPN-9 consists of receiver-transmitter, power supply, antenna and connectors. Beacon life is 50 hr; 15-min operation with battery. American Machine & Foundry Co., 261 Madison Ave., New York 16, N. Y.

Time Delay Relay. Electronic type needs no warmup and consumes about 1 watt. Hermetically sealed unit provides accurate delays of 3 millisecc to 30 sec. Weight is 9 oz. G. C. Wilson & Co., 1915 Eighth Ave., Huntington, W. Va.

Accelerometer. Model GDM weighs 14 oz and measures lateral accelerations in two mutually perpendicular planes. Ranges of ± 2 g to ± 30 g. Silicone oil damped. Genisco, Inc., 2233 Federal Ave., Los Angeles 64, Calif.

Mechanical

Fast-Acting Valve. Pneumatic-type Series 200 is available as piston-operated or diaphragm-operated. Designed to handle air, helium, argon, or nitrogen at pressures up to 10,000 psi. Pressure drops of 6000 psi under flow. Minneapolis-Honeywell Regulator Co., Valve Div., 2753 Fourth Ave. S., Minneapolis 8, Minn.



Propellant Pump. Pumps normal propyl nitrate at 260 F. Output: 0.5 gpm. General Electric Co., Aircraft Products Dept., Schenectady 5, N. Y.

Bubble-Tight Needle Valve. Available in tube or pipe sizes. PVC, Teflon, Kel-F or stainless steel construction. Chemtrol Corp., 1513 W. El Segundo Blvd., Compton, Calif.

Test

Tape-On Temperature Resistor. For telemetering, resistor is applied by Mylar tape. Ranges of -300 to 400 F. Accuracy is ± 2 per cent of full-scale range; precision is ± 0.5 per cent of full scale. Trans-Sonics, Inc., Box 328, Lexington, Mass.

Moisture Monitor. Type 26-301 has

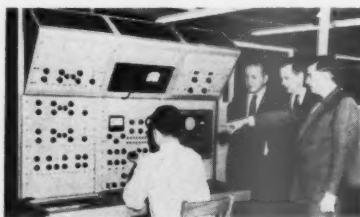
full scale range of 0-1000 ppm. Output can be telemetered. Operates on 115-125 v ac, 50-60 cycle. Consolidated Electrodynamics Corp., 300 N. Sierra Madre Villa, Pasadena, Calif.

Flow Rate Indicator. Model FR-301 is transistorized and telemeters propellant flow on a 0-5 volt signal. 28-v supply system. Waugh Engineering Co., 7842 Burnet Ave., Van Nuys, Calif.



Tape Recorder. Miniature (4 in. wide, 5 in. high, 2 1/4 lb) unit used in HTV missile records flight data. Norris-Thermador Corp., 5215 S. Boyle, Los Angeles 58, Calif.

Borescopes. Periscope-type with built in flashlight can be inserted through openings as small as 0.1 in. diam and view surfaces up to 20 ft away. National Electric Instrument Co., Elmhurst, N. Y.



Complex-Motion Tester. For vibration research in missiles, Model T67 compensation console includes amplifier, hf electrodynamic exciter, and control console. MB Mfg. Co., New Haven, Conn.

Dynograph Recorders. Direct-writing oscillographs are available in ink, heat sensitive or electric sensitive tracings with either curvilinear or rectilinear coordinates. Console, rack or portable models. Offner Electronics, 5320 N. Kedzie, Chicago 25, Ill.

Materials

Conductive Silicone. X-1516 elastomers feature uniform resistivity (13-16 ohm-cm) even after flexing. Conductivity can be varied by choice and amount of carbon black filler. Silicones Div., Union Carbide & Carbon Corp., 30 E. 42 St., New York 17, N. Y.

Chlorofluorocarbon Grease. Halocarbon Series 25-10 can be used to protect against nitric acids, 90 per cent hydrogen peroxide, oxygen, etc. Temperature range of 30-275 F. Halocarbon Products Corp., 82 Burlews Court, Hackensack, N. J.

Solvent Resistant Grease. Impervious to washing action of almost all petroleum and chlorinated solvents. Readily pumped at low temperatures. Pennsylv-

vania Refining Co., 2686 Lisbon Rd., Cleveland 4, Ohio.

Thin-Wall Tubing. Welded stainless steel for walls of 0.005 in. for 1/4-in. OD to 0.015 in. for 1 1/2-in. OD. Continuous lengths to 200 ft. Universal Tube Corp., 2133 S. Kedzie Ave., Chicago 23, Ill.

Zippertubing. Air Force approved wire enclosure can be unzipped or permanently sealed. PVC plastic. ID's are from 1/2 in. to 4 1/2 in. in steps of 1/8 in. Lengths of 20-1000 ft. W. A. Plummer Mfg. Co., 752 San Pedro St., Los Angeles, Calif.

Product Literature

Evaporograph. Direct thermal imaging device is described in Bulletin RD515. Applications outlined are combustion equipment, bond strength, and general temperature monitoring. Baird Associates-Atomic Instrument Co., 33 University Road, Cambridge 38, Mass.

Magnesium Alloy. Properties of HK-31XA sheet and plate are given in this 37-page booklet. Dow Chemical Co., Magnesium Dept., Midland, Mich.

Instruments. Brochure illustrates miniature and standard temperature and pressure-sensing devices including pressure probes, thermocouples, and accessories. Aero Research Instrument Co., 315 N. Aberdeen St., Chicago 7, Ill.

Castable Refractories. Form 1992 contains technical information on Alundum 33-I and 33-HD for protection to 3300 F. Norton Co., Worcester 6, Mass.

Photographic Instrumentation. A series of information sheets gives specs on instrument cameras, aerial and data cameras, accessories, etc. Gordon Enterprises, 5362 N. Cahuenga Blvd., North Hollywood, Calif.

Scorpion Rocket. Illustrated brochure gives details of the Napier rocket. D. Napier & Son Ltd., Acton, London, W3, England.

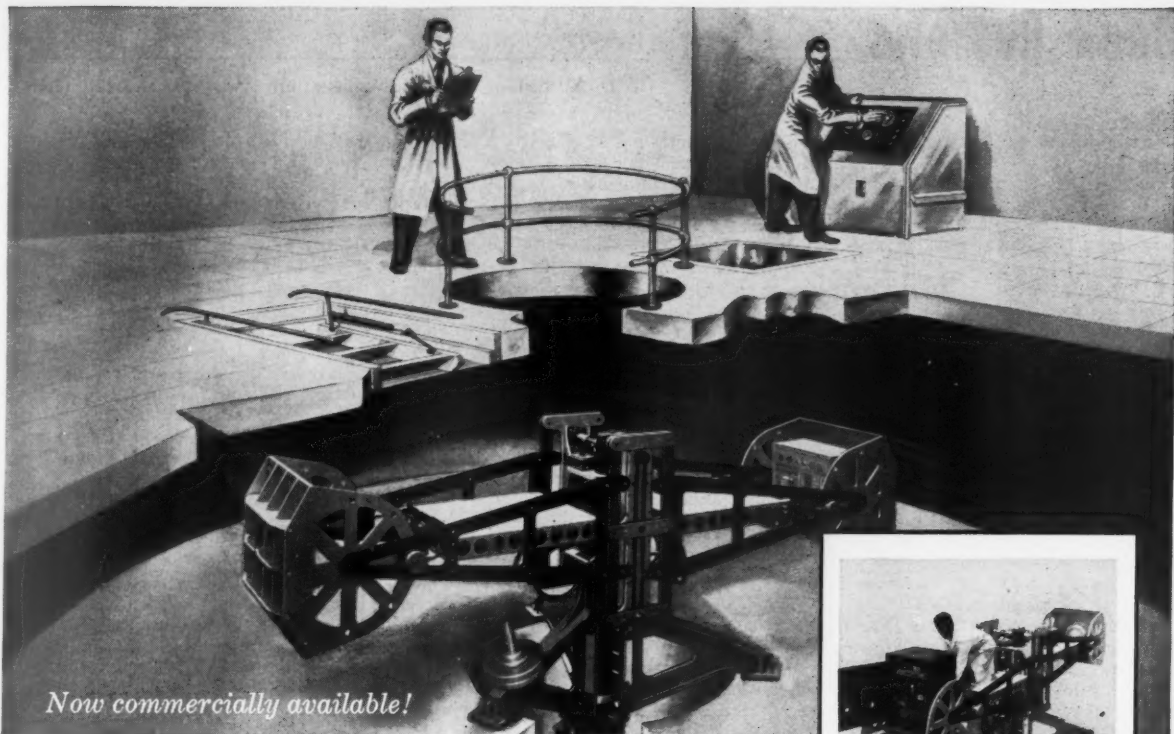
Aeronautical Research. This 68-page book is entitled "A Decade of Research, 1946-1956" and covers aerodynamics, structure, electronics, propulsion, and weapons systems. Cornell Aeronautical Laboratory, Inc., Cornell Univ., Buffalo 21, N. Y.

Ramjet Principles. A detailed, illustrated booklet is entitled "An Engineer's Ramjet Primer." Wright Aeronautical Div., Curtiss-Wright Corp., Wood Ridge, N. J.

Missile Aerophysics. GEZ-1741 is "Some Aerophysics Problems Connected with Hypersonic Flight, Systems Engineering, and Hypersonic Experimentation." GEZ-1742 contains "The Integration of Systems Test," "Missile Aerophysics," and "Structural Frontiers." General Electric Co., Apparatus Sales Div., Schenectady 5, N. Y.

Sled Propulsion. Reviews problems of ARDC rocket sleds in "Second Experimental Track Symposium—Seminar Reports and Abstracts of Papers," PB 121306. Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. \$1.50.

WFNA Resistant Coating. "Development of an Organic Lacquer Resistant to Fuming Nitric Acid" describes modification of Kel-F. PB 121005. Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. \$1.25.



Now commercially available!

New Genisco Centrifuge subjects two 300 lb. assemblies to 100 G's

Genisco's Model E185 G-Accelerator, capable of subjecting complete electronic and mechanical systems to G-loadings that simulate actual flight operation, incorporates numerous unique features that simplify operation, reduce servicing, and allow precision testing to meet the most stringent military specifications.

The absence of belts, pulleys, and gears permits smooth and vibration-free rotation of the 12-foot rotor so that delicate inertial guidance systems can be tested. The machine is rugged enough, however, to accommodate proof-load testing.

Operation is unusually simple. Operator responsibility has been minimized, with many operational functions being accomplished automatically. Numerous built-in safety features afford maximum protection to both personnel and the machine.

These design features, plus wide flexibility in the use of the machine, reduce maintenance requirements, and together with low initial cost make the Model E the best large centrifuge currently on the market. Complete specifications will be sent on request.

SMOOTH, CONSTANT ROTATION—Hydraulic drive system permits a clean, compact design. Problems of backlash, gear noise, and frequent lubrication are eliminated. Wow and drift during a one-minute period are less than 0.5% of the operating rate at any speed.

SIMPLE SPEED CONTROL—A single hand-wheel, located on a remote-control console, determines boom speed. Speed adjustments are made quickly without reading complicated scales or dials.

AUTOMATIC DYNAMIC BALANCING—The boom seeks a dynamically balanced condition automatically. Manual computation to determine centers-of-gravity is eliminated.

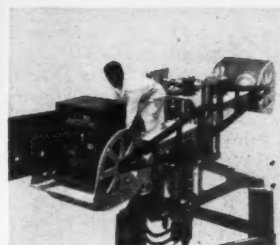
BOOM SPEED EASILY MEASURED—Coarse speed indication is accomplished by a specially-calibrated tachometer, accurate to within 1% of actual speed. Precision measurements are provided by a pulser/elec-

tronic counter, on a 4-decade digital display.

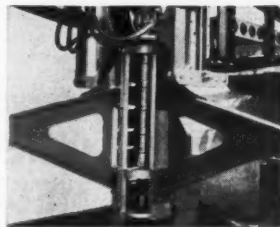
REDUCED HORSEPOWER REQUIREMENTS—By utilizing aircraft design techniques and enclosing the structure in an aerodynamically clean compartment, horsepower requirements are reduced to 15 h.p. for a 100-G machine.

BUILT-IN SAFETY FEATURES—Eight safety interlocks, including three which are key-operated, prevent the machine from being started inadvertently. Removal of any key renders the machine inoperable, permitting the operator to make adjustments to the test object in absolute safety.

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SLIP RING SYSTEM—A total of 48 slip rings are provided as standard equipment in a configuration of 24 unshielded leads rated at 14 amperes maximum, and 24 shielded leads rated at 1 ampere. Brush holders have been removed in the above photograph.



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Book Reviews

Ali Bulent Cambel, Northwestern University, Associate Editor

Progress in Cosmic Ray Physics, edited by J. G. Wilson, North-Holland Publishing Co., Amsterdam, 1956; Interscience Publishers, New York, 420 pp. \$10.50.

Reviewed by S. F. SINGER
University of Maryland

The study of cosmic rays has advanced so rapidly in the last decade that it has become impossible even for the specialist to keep up with the many papers published in physics journals in various countries. Also the subject of cosmic rays has now subdivided into many specialized aspects, some of them dealing with the nuclear physics problems of high energy particles, some with the origin of cosmic rays and its distribution near the earth and in the universe. Inevitably this has involved an ever-increasing group of physicists in the cosmic ray field, on the one hand nuclear physicists working on new types of elementary particles with high energy accelerators, on the other hand astrophysicists and astronomers who are concerned about the phenomena occurring in the atmosphere of stars and in the interstellar space where acceleration of cosmic rays probably takes place.

The need has therefore been great for review articles which summarize the

current state of knowledge in a certain field of cosmic ray investigations. Under the capable editorship of J. G. Wilson of the University of Leeds in England several volumes have been published containing contributions by outstanding specialists which summarize the state of research in their field. The present volume, the third in this series, contains four chapters. K. Greisen of Cornell University discusses experiments, their interpretation and the theory of the so-called extensive air showers, phenomena which are produced by cosmic rays of extremely high energies, between 10^{14} and 10^{18} ev. In complicated nuclear and electromagnetic interactions the original particle produces at lower altitudes in the atmosphere often millions of secondary particles which will hit the earth like a shower over an area of about 100 yards radius; hence the name.

The second chapter, written by H. S. Bridge of MIT, summarizes present knowledge of unstable elementary particles with mass between the electron and the proton (the so-called mesons) and with mass greater than that of the proton (the hyperons). These particles are all produced in high energy nuclear interactions of cosmic rays either with atoms in the atmosphere or in this case with atoms in photographic plates which are used to detect these events. It is thought

that the problem of nuclear forces is closely tied up with the nature of these particles.

The third chapter, by R. W. Thompson of Indiana University, discusses yet another group of unstable particles observed in the cosmic radiation, namely, those carrying no charge. They too play an important part in the theory of nuclear forces.

The last chapter, by G. Puppi of the University of Bologna, considers the problem of cosmic rays in the atmosphere and investigates what happens to the cosmic ray energy which enters at the top of the atmosphere. Professor Puppi shows that a certain fraction of the energy goes to produce the unstable mesons, many of which reach the bottom of the atmosphere and even penetrate deep down into the earth. Another fraction of the energy goes into electrons and photons and eventually appears as ionization in the atmosphere. Another fraction is in the nucleonic component, some of the energy being used to break up atmospheric nuclei. Finally in many of these interactions energy escapes in the form of neutrinos and is never recovered. Almost one-fourth of the energy goes into neutrinos, about 60 per cent into ionization in the atmosphere, about 10 per cent into breaking up nuclei, and the remainder penetrates into the earth.

Methods in Numerical Analysis, by Kaj L. Nielson, Macmillan, New York, 1956, 382 pp.

Reviewed by R. M. LARSON
University of Minnesota

Due to the recent development of high speed digital computers most of the current books on numerical analysis place emphasis on those numerical techniques that are important to high speed machine computation. These techniques, usually of the iterative type, are inefficient when used for hand calculations because they do not use the factor of human judgment. Recognizing this fact, Mr. Nielson has written a book for the person desiring to do numerical computation on a desk calculator. The book has nine chapters covering four basic topics: Interpolation and numerical integration, classical and operational methods, solution of algebraic and differential equations, and least-squares methods and curve fitting. Also included is a collection of coefficient tables containing numerical values for many kinds of interpolation and integrating polynomials. The text places considerable emphasis on setting up calculation schemes or programs for the numerical work and many fine examples illustrate this important phase of the solution.

The book is arranged in a manner particularly suited to self-instruction. Each chapter begins with the basic, generally useful techniques, followed by the more powerful, but less general, methods. The inclusion of many nu-

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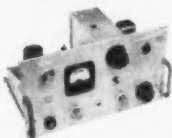
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TECHNIQUES and DEVELOPMENTS in oscillographic recording

PHASE SENSITIVE DEMODULATOR PRE-AMPLIFIER PROVIDES A DC VOLTAGE PROPORTIONAL TO AN INPHASE COMPONENT OF AN AC VOLTAGE WITH RESPECT TO A REFERENCE.

THE measurement of the amplitude of an AC voltage component is often necessary in performance studies of servo systems or of suppressed carrier signals over the carrier frequency range from 60 to 10,000 cps. In such cases the demodulator responds to inphase signals and rejects quadrature signals.



A circuit with these characteristics for use in an oscillographic recording system can be seen in the Model 150-1200 Servo Monitor (Demodulator) Preamplifier. It was developed by Sanborn as one of twelve interchangeable, plug-in front ends for "150" Series equipment,

to be used with the appropriate Driver Amplifier-Power unit in any channel of a "150" system. Elements comprising the circuit from input to output, include: compensated stepped attenuator and cathode follower input circuit, phase inverter, push-pull mixer and demodulator stages, differential DC output amplifier and low pass filter. In addition, the chassis contains a VTVM to facilitate accurate adjustment of the reference voltage, and an overload indicator which lights a warning lamp when excessive quadrature voltages exist.

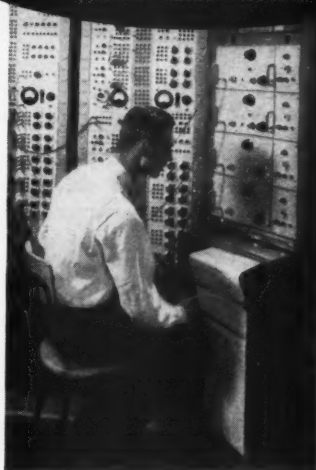
Adaptability to a fairly wide variety of applications is accomplished through broad input voltage, reference voltage and frequency ranges. In order, these are 50 mv to 50 v (for full scale 5 cm deflection), 10 v to 125 v; 60 cps to 10kc. Rise time with low frequency plug-in demodulation filter is 0.1 seconds; with high frequency filter, 0.01 seconds. Quadrature rejection is better than 100:1; for carrier frequencies up to 5000 cycles.

Two representative uses of the Servo Monitor Preamplifier are in the design and adjustment of servo systems, and with instruments used in the design, development or adjustment of other apparatus. The first is illustrated by use of the Preamplifier and associated equipment in the recording of the output shaft amplitude and driving frequency of an AC positional servo; the second by recordings made with a similar setup of the difference between output signals from a gyroscopically-controlled stabilizing device and the "pitch" and "roll" signals generated by a "Scorsby Table" used for testing the device under dynamic conditions.

For a detailed discussion of the principles and design considerations involved in the Servo Monitor Preamplifier, refer to the February, 1955 issue of the Sanborn RIGHT ANGLE, for Dr. Arthur Miller's article on "Measurements with the Servo Monitor Preamplifier."

Technical literature and engineering assistance on specific problems are always available from our engineering department.

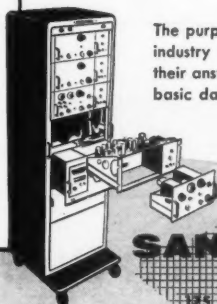
FROM SANBORN



BASIC FACTORS IN SELECTING OSCILLOGRAPHIC RECORDING EQUIPMENT

WHEN considering any oscillographic system or equipment for your application, three useful "yardsticks" to apply are (1) the recording method, (2) equipment adaptability, and (3) variety of equipment available. Here are the answers to the three, as they apply to Sanborn systems. In the record, rectangular coordinates accurately correlate multiple traces, simplify interpretation and eliminate errors. Permanent traces, produced by a hot ribbon stylus without ink, provide sharp peaks and notches, and clearly reveal all signal changes. One percent linearity results from current feedback driver amplifiers and high torque galvanometers of new design; maximum error is $\frac{1}{4}$ mm in middle 4 cm of chart, $\frac{1}{2}$ mm across entire chart. From the standpoints of "adaptability" and "variety", Sanborn "150" equipment offers the versatility of 13 different plug-in front ends for any basic system . . . the choice of one- to eight-channel systems . . . the variety of nine chart speeds, timing and coding controls, console or individual unit packaging . . . availability of equipment as either complete systems or individual amplifier or recorder units.

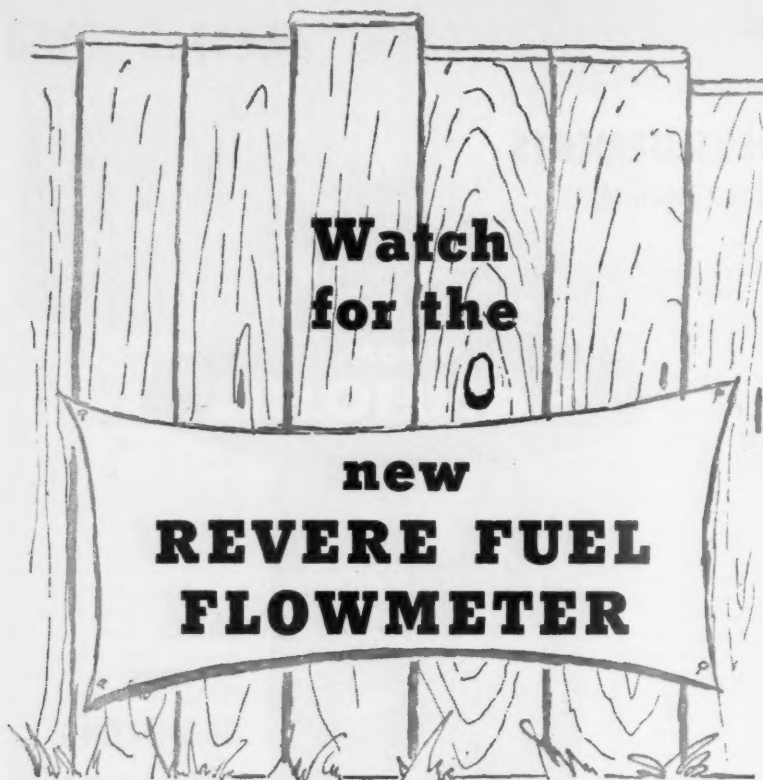
The purpose of the foregoing information is to better acquaint industry with typical oscillographic recording problems and their answers, design considerations in Sanborn equipment, and basic data on what Sanborn makes and how it is being used.



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merical examples and exercises furthers this purpose. The text is also useful as a handbook of numerical analysis. The indexing is done well and except for a list of articles on numerical analysis the bibliography is quite representative. As is the rule in most reference books, proofs and derivations consist mainly of an outline of the actual steps, augmented by explanatory remarks to clarify the method. However, since the purpose of this book is to impart a working knowledge of numerical methods, the lack of mathematical rigor is not a hindrance.

Three important topics that are given only brief coverage in the book are relaxation, iteration, and perturbation techniques. Relaxation methods offer a simple, repetitive, self-correcting scheme for solving the systems of simultaneous equations that arise so often in physical problems. Iteration techniques are important because of their almost universal applicability to any mathematical problem. Also, because of their simplicity, they are easily adapted to high speed computers. The perturbation theory, when applied to numerical calculations, becomes a powerful tool for studying or forcing convergence of many iterative techniques. More extensive treatments of the theory and application of these methods are readily available, and a number of references to this literature are included in the bibliography.

Book Notices

Vector Analysis, by Homer E. Newell, Jr., McGraw-Hill, New York, 1955, 216 pp. \$5.50. A book written for engineers and scientists so that they may develop skills in the algebra and the calculus of vectors.

Electronics, by A. W. Keen, Philosophical Library, New York, 1956, 632 pp. \$7.50. A popular book on electronics describing the characteristics of electrons and their application to science and industry.

There Is Life on Mars, by Earl Nelson, The Citadel Press, New York, 1956, ix + 152 pp. \$3. A book for the layman about Mars.

Man and the Winds, by E. Aubert de la Rue, translated by Madge E. Thompson; Philosophical Library, New York, 1955, 206 pp. \$16. A book written for the laymen describing winds as they affect mankind. Pleasant to read, it should give the reader a feeling for the importance of winds, their possible uses, benefits, and drawbacks.

The Sound Barrier, by Neville Duke and Edward Lanchbery, 6th edit., Philosophical Library, New York, 1955, 129 pp. \$4.75.

Zirconium, by G. L. Miller, Butterworths Scientific Publications, London, 1954, 382 pp. \$7.50. This is the second in a series of books dealing with the metallurgy and the properties of the rarer metals. It includes material about the following aspects of zirconium and its compounds: History and occurrence, use, extraction, production structure, reactions, fabrication, and powder metallurgy.

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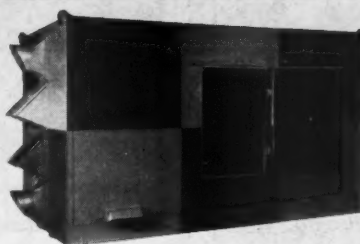
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Technical Literature Digest

M. H. Smith, Associate Editor, and M. H. Fisher, Contributor
The James Forrestal Research Center, Princeton University

Jet Propulsion Engines

Analysis of Systems Used for Speed Governing Turbojet Engines, by Jack O. Nash, *Aero Digest*, vol. 73, Dec. 1956, pp. 14-19.

Procedures for the Determination of the Particle Size Retention Characteristics, the Flow Resistance Characteristics, and the Dirt Handling Capabilities of Fuel Filters for Aircraft Jet Engines, by C. M. Price and Douglas Dow, (Final Report), *Detroit Testing Lab., Inc., Rep. no. 0607-E-1*, June 7, 1955, 42 pp.

Final Summary Report of the Aerothermopressor Project, *Mass. Inst. Tech., Gas Turbine Lab.*, Sept. 1956, 146 pp.

Contribution to the Study of Supersonic Axial Compressors, by Pierre Schwaar, *NACA TN-41357*, Nov. 1956, 17 pp. (Translated from *Zeitschr. Angew. Math. Phys.*, vol. 4, no. 2, 1954.)

Free Flight Performance of 16-Inch Diameter Supersonic Ram Jet Units. I. Four Units Designed for Combustion Chamber Inlet Mach Number of 0.2 at Free Stream Mach Number of 1.6 (Units A-2, A-3, A-4, and A-5), by William W. Carlton and Wesley E. Messing, *NACA RM E9F22*, Sept. 1949, 51 pp. (Declassified by authority of *NACA Res. Abstracts*, 101, May 25, 1956, p. 8.)

Turbojet Engine Control System Study, Progress Report for the Period Ending

Feb. 29, 1956, *Gen. Electric Co., Aircr. Products Dept.*, TR 55A017-4, Feb. 1956.

Two-Dimensional Low-Speed Cascade Investigation of NACA Compressor Blade Sections Having a Systematic Variation in Mean-Line Loading, by John R. Erwin, Melvyn Savage and James C. Emery, *NACA TN 3817*, Nov. 1956, 129 pp.

Design Factors for 4 by 8 Inch Ram Jet Combustor, by Donald W. Male and Adolph J. Cervinka, *NACA RM E9 F09*, Aug. 1949, 47 pp. (Declassified by authority of *NACA Res. Abstracts* 101, May 25, 1956, p. 8.)

Preliminary Investigation of Effects of Combustion in Ramjet on Performance of Supersonic Diffusers. III. Normal Shock Diffusers, by Albert H. Schroeder and James F. Connors, *NACA RM E8J18*, Dec. 1948, 15 pp. (Declassified by authority of *NACA Res. Abstracts* 102, June 22, 1956, p. 15.)

Rocket Propulsion Engines

Reliability Concepts in Rocket Power Controls Design, by H. L. Coplen, Jr., *Aerojet Gen. Corp. Tech. Paper 102A*, Nov. 1956, 11 pp. (also *ARS Prepr.* 369-56).

The Influence of the Construction of a Turbopump on the Flight Performance of a Large Rocket, by H. H. Kolbe, *Proc. 5th Intern. Congr. Astron.*, 1954, Vienna, Springer, 1955, pp. 59-71 (in German).

Calculation of Step Rockets, by M. Vertregt, *Proc. 5th Intern. Congr. Astron.*, 1954, Vienna, Springer, 1955, pp. 157-161.

On the Nomenclature of Weight Values for Step Rockets, by G. Pirquet, *Proc. 5th Intern. Congr. Astron.*, 1954, Vienna, Springer, 1955, pp. 162-167 (in German).

On Automatic Internal and External Control of Long Range Rockets, by J. M. J. Kooy, *Proc. 5th Intern. Congr. Astron.*, 1954, Vienna, Springer, 1955, pp. 168-177.

Design Outline for Altitude Rockets with Compressed Gas Distribution, by R. Engel, *Proc. 5th Intern. Congr. Astron.*, 1954, Vienna, Springer, 1955, pp. 178-182 (in German).

On the Influence of Recombination on the Performance of Liquid Propellant Rockets, by U. T. Bodewadt, *Proc. 5th Intern. Congr. Astron.*, 1954, Vienna, 1955, pp. 183-187 (in German).

A New Approach to Rocket Power, by E. A. Smith, *Aeronautics*, vol. 35, Dec. 1956, p. 29.

An Extension of the Theory of the Optimum Burning Program for the Level Flight of a Rocket Powered Aircraft, by Angelo Miele, *Purdue Univ. School of Aeron. Engng., Rep. A-56-1*, June 1956, 49 pp. (*AF Off. Sci. Res. TN 56-302*).

Optimal Programming of Rocket Thrust Direction, by D. F. Lawden, *Astron. Acta*, vol. 1, no. 1, 1955, pp. 41-56.

Thermodynamic Theory of Rocket



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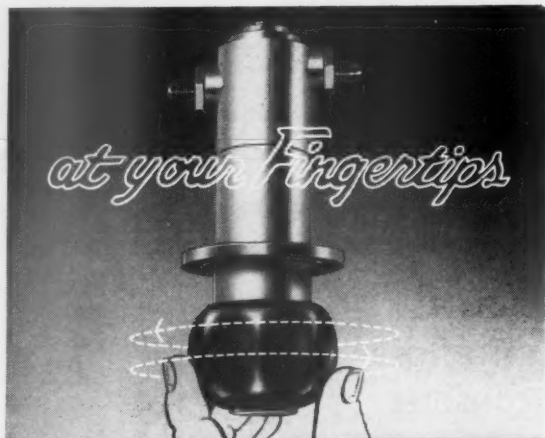
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Motor with Hydrazine and Nitric Acid as
Fuels, by J. M. J. Kooy, *Astron. Acta*, vol.
1, no. 4, 1955, pp. 157-165.

Heat Transfer and Fluid Flow

Investigation of Transient Pool Boiling
Due to Sudden Large Power Surge, by
Robert Cole, *NACA TN* 3885, Dec. 1956,
44 pp.

Rapid Determination of Core Dimen-
sions of Crossflow Gas-to-Gas Heat Ex-
changers, by Anthony J. Diagulia and
John N. B. Livingood, *NACA TN* 3891,
Dec. 1956, 19 pp.

The Numerical Solution of the Heat
Conduction Equation Occurring in the
Theory of Thermal Explosions, by J. W.
Enig, D. Shanks and R. W. Southworth,
NAVORD Rep. 4377, Nov. 1956, 11 pp.

On the Contribution of Turbulent Bound-
ary Layers to the Noise Inside a Fuselage,
by G. M. Corcos and H. W. Liepmann,
NACA TM 1420, Dec. 1956, 43 pp.

The Flow of a Flashing Mixture of Water
and Steam at High Pressures, by P. N.
Haubenreich, *Atomic Energy Comm.*, CF-
55-5-200, May 1955, 89 pp.

Thermal Conductivities of Liquids:
New Determinations for Seven Liquids
and Appraisal of Existing Values, by
A. R. Challoner and R. W. Powell, *Proc.
Royal Soc.*, vol. A 238, Dec. 1956, pp. 90-
106.

Introduction to Irreversible Processes,
by J. deBoer, *Wisconsin Univ. TR WIS-*
AF-2, 1956, 27 pp.

Preliminary Measurements of Non-
steady Velocities in a Single Stage Axial-
Flow Compressor, by Hsuan Yeh, Harry
M. Crooner and Donald E. Andrews (The
Johns Hopkins Univ.), *Wright Air Dev.
Center, TR* 55-249, June 1956, 41 pp.

Spreading Characteristics of a Jet Ex-
panding from Choked Nozzles at Mach
1.91, by Morris D. Rousso and L. Eugene
Baughman, *NACA TN* 3836, Dec. 1956,
27 pp.

Chemical Processes as Methods of
Achieving High Temperatures, by David
Altman, *Calif. Inst. Tech., Jet Propulsion
Lab., Mem.* 20-132, June 1956, 19 pp.

On the Transport of Translation Energy
by Short Time Processes, by H. J.
Kaeppler, *Astron. Acta*, vol. 1, no. 3,
1955, pp. 111-119 (in German).

Combustion

Research in the Combustion of Liquid
and Gaseous Fuels. *Battelle Mem. Inst.*
Final Quarterly Report, Sept. 1 to Nov.
30, 1956.

Bibliography on Ignition and Spark Igni-
tion Systems, by George F. Blackburn,
Nat. Bur. Stands. Circ. 580, Sept. 1956, 15
pp.

On the Changing Size Spectrum of Par-
ticle Clouds Undergoing Evaporation,
Combustion or Acceleration, by Ascher
H. Shapiro and Alve J. Erickson, *Gas
Turbine Lab., Mass. Inst. Tech., Cam-
bridge*, April 1956, 42 pp.

Interference during Burning of Body-
Centered Cubic Arrays of Nine Fuel Drop-
lets in Air-Spray Formation and Evapora-
tion, by J. N. Kanevsky, *Daniel and
Florence Guggenheim Jet Prop. Center,
Calif. Inst. Tech., Pasadena*, Thesis,
June 1956, 60 pp. (TR No. 15).

Probing Into Cool Flames, Part II,
Dynamic Studies at Short Residence
Times, by K. G. Williams, F. J. Woods

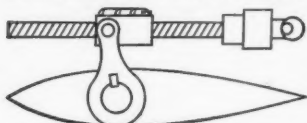
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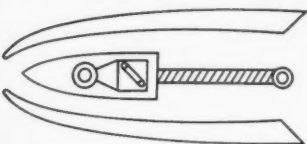
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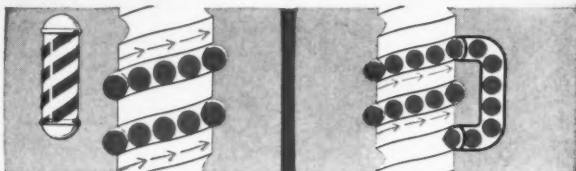
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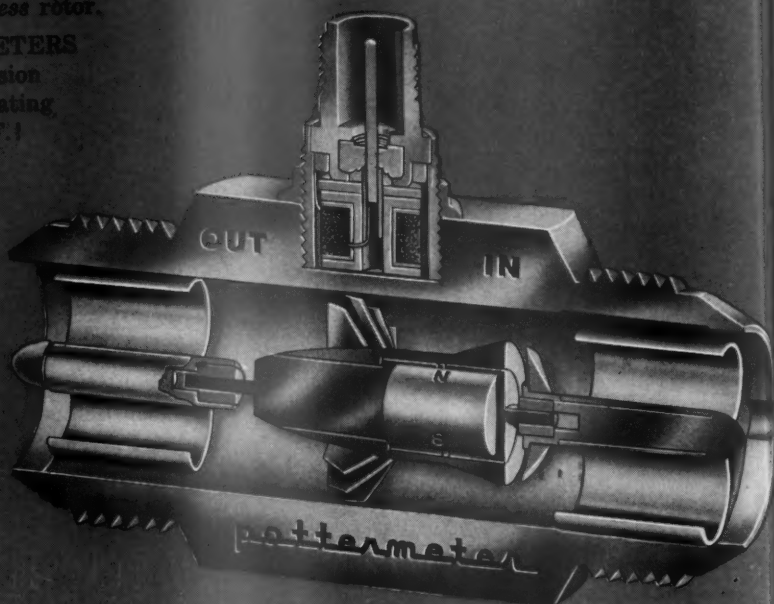
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and others, *Naval Res. Lab., Washington, D. C.*, March 26, 1956, 16 pp. (Rep. 4651).

Research on Combustion Phenomena at High Pressures, by R. Edse, W. A. Strauss, and M. Fong, *Ohio State Univ. Res. Foundation, Columbus, Quarterly Progress Rep. No. 3*, Nov. 1, 1955-Jan. 31, 1956, March 28, 1956, 15 pp.

Generalized Equations and Procedures for the Calculation of Detonation Parameters—Case I, Ideal Gaseous Mixtures, by Robert G. Dunn and Bernard T. Wolfson, *Aeron. Res. Lab. Wright Air Dev. Center, Wright-Patterson Air Force Base, Ohio, Report on Ramjet Technology*, March 1956, 79 pp. (TN WADC-TN-54-13).

A Thermal Equation for Flame Quenching, by A. E. Potter, Jr., and A. L. Berlad, *NACA Rep. 1264*, 1956, 7 pp.

Photographic Studies of Preignition Environment and Flame Initiation in Turbojet-Engine Combustors, by David M. Straight and J. Dean Gernon, *NACA RM E52111*, Feb. 1953, 40 pp. (Declassified by authority of *NACA Res. Abstracts* 108, Nov. 2, 1956, p. 13.)

Combustion Studies of Astrophysical Significance. 1. A Survey of the General Mechanics of Flame Propagation, and of Relevant Experimental Techniques, by G. V. Marr, *Western Ontario Univ. (Canada), Sci. Rep. 23*, May 1956, 56 pp. (*AF Off. Sci. Res. TN 56-484*).

Visible Emission Spectra of Two-Stage Flames of Diethyl Ether Produced in Flat-Flame Burner, by W. G. Agnew and J. T. Agnew, *Indust. Engng. Chem.*, vol. 48, Dec. 1956, pp. 2224-2231.

Burning Rate Studies. Part 7. Effect of Chemical Composition on the Consumption Rate of the System 2-Nitropropane-Nitric Acid, by A. Greenville Whittaker and Harry Williams, *NAVORD Rep. 1999, Pt. 7 (NOTS 1470)* May 1956, 12 pp.

Determination of the Dissociation Constants and Heats of Formation of Molecules of Flame Photometry. Part 1. Equilibrium in Flame Gases and General Kinetic Considerations, by T. M. Sugden, *Trans. Faraday Soc.*, vol. 52, Nov. 1956, pp. 1465-1474.

Thermodynamic Properties of the System Methane Carbon Monoxide at 90.67° K., by V. Mathot, L. A. K. Staveley, J. A. Young and N. G. Parsonage, *Trans. Faraday Soc.*, vol. 52, Nov. 1956, pp. 1488-1499.

Hydrazine Decomposition Flames at Sub-Atmospheric Pressures, by A. R. Hall and H. G. Wolfhard *Trans. Faraday Soc.*, vol. 52, Nov. 1956, pp. 1520-1525.

Fuels, Propellants and Materials

The Design of Brittle-Material Blade Roots Based on Theory and Rupture Tests of Plastic Models, by Andre J. Meyer, Jr., Albert Kaufman, and William C. Caywood, *NACA TN 3773*, Sept. 1956, 46 pp. (supersedes *NACA RM E53C12*).

Further Investigation of the Feasibility of the Freeze-Casting Method for Forming Full-Size Infiltrated Titanium Carbide Turbine Blades, by E. M. Grala, *NACA TN 3769*, Oct. 1956, 19 pp.

On the Hydrogen Bond Contribution to the Heat of Vaporization of Aliphatic Alcohols, by A. Bondi and Donald J. Simkin, *J. Chem. Physics*, vol. 25, Nov. 1956, p. 1073-1074.

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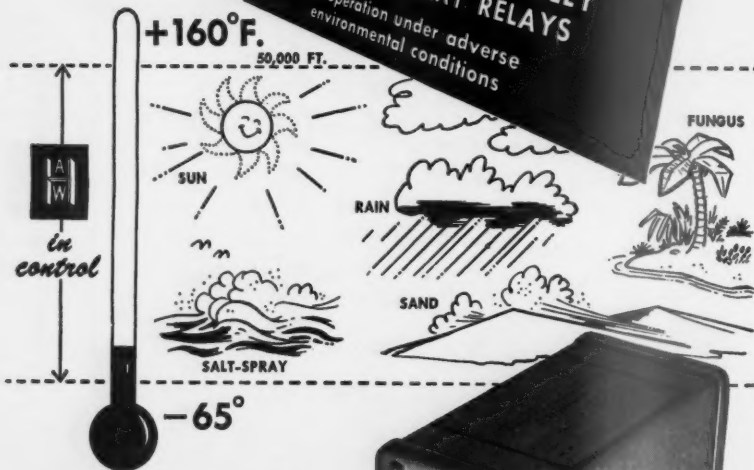
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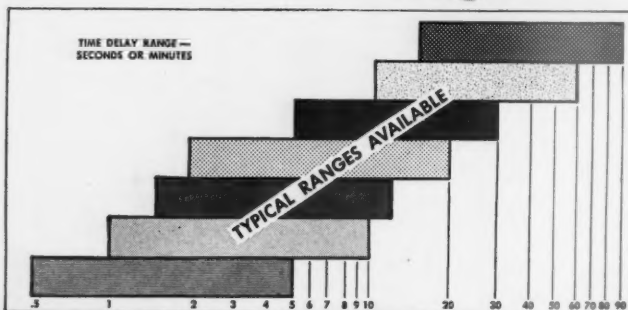
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Nitrogen Dioxide, by Willis A. Rosser, Jr. and Henry Wise, *J. Chem. Physics*, vol. 25, Nov. 1956, pp. 1078-1079.

Improved Silicon Carbide for High Temperature Parts, by K. M. Taylor, *Materials and Methods*, vol. 44, no. 4, Oct. 1956, pp. 92-95.

High Strength Nickel-Base Alloy for High Temperature Service, *Materials and Methods*, vol. 44, no. 4, Oct. 1956, pp. 147-148.

Metallurgy of Titanium, by Marion G. Mastin, *Ordinance*, vol. XLI, no. 210, Nov.-Dec., 1956, pp. 432-434.

Metals in the Atomic Age, by Henry H. Hausner, *Ordinance*, vol. XLI, no. 210, Nov.-Dec. 1956, pp. 557-558.

Investigations of the Electrical and Physical Characteristics of Aircraft Fuels, by Richard E. Johnson and Floyd A. Andrews, Report on Engine Instruments. May 1954 to March 1955, *Minneapolis-Honeywell Regulator Co., Minneapolis*, Jan. 1956, 89 pp. (Tech. Rep. WADC-TR-55-219).

A Study of Incorporation of High Energy Substances in Conventional Type Fuel Materials by Physical Inclusion, by D. Horvitz, F. R. Benson and others, Final Technical Report, Aug. 23, 1955-March 31, 1956, *Metaelectro Corp., Laurel, Md.*, April 1956, 36 pp. (Tech. Rep. AFOSR-TR-56-17).

Research on Ultra-Energy Fuels for Rocket Propulsion, by L. Baum, H. Graff and others, Final report 1149, July 1954-June 1956, *Aerojet-General Corp., Azusa, Calif.*, July 31, 1956, 47 pp. (Tech. Rep. AFOSR-TR-56-346).

Bibliography of Creep for Structural Engineers, by Joseph Kempner and N. J. Hoff, Report on Structural Testing of Elevated Temperatures, WADC Pilot Plant.

An Experimental Evaluation of Several Design Variations of Hollow Turbine Blades for Expendable Engine Application, by W. C. Morgan and R. H. Kemp, *NACA RM E54K23*, Feb. 1955, 33 pp. (Declassified from Confidential by authority of *NACA Res. Abstracts* 109, Nov. 20, 1956, p. 9.)

Performance of As-Forged, Heat-Treated, and Overaged S-816 Blades in a Turbojet Engine, by J. W. Weeton, F. J. Clauss and J. R. Johnston, *NACA RM E54K17*, March 1955, 51 pp. (Declassified from Confidential by authority of *NACA Res. Abstracts* 109, Nov. 20, 1956, p. 9.)

Fluorine-Ammonia Combustion, by D. E. Mann and G. T. Armstrong, *Wright Air Dev. Center, Tech. Rep. 55-365*, 1955. (*ASTIA AD 97331*.)

Mean Tangential Stress in a Pressurized Rotating Grain of Hollow Cylindrical Shape, by L. Bankston and W. Cohen, *NAVORD Rep. 3442 (NOTS 1044)*, Oct. 1956, 7 pp.

Effects of Additives on Pressure Change in Thermal Reactions of Acetylene, by Gene Morrow and R. C. Anderson, *Texas University, Tech. Note 32 (AF OSR-TN-56-493; ASTIA AD 110 307)*, Oct. 1956, 11 pp.

Exploratory Studies of the Acetylene Ethylene Oxide Combustion Systems, by Robert Pratt, M. S. B. Munson and Robbin C. Anderson, *Texas University, Tech. Note 33 (AF OSR-TN-56-502; ASTIA AD 110-502)*, Oct. 1956, 5 pp.

Ignition Delays of Some Nonaromatic Fuels with Low-Freezing Red Fuming Nitric Acid in Temperature Range -40° to -105°F., by Riley O. Miller, *NACA RM E52K20*, Jan. 1953, 17 pp. (Declassified)

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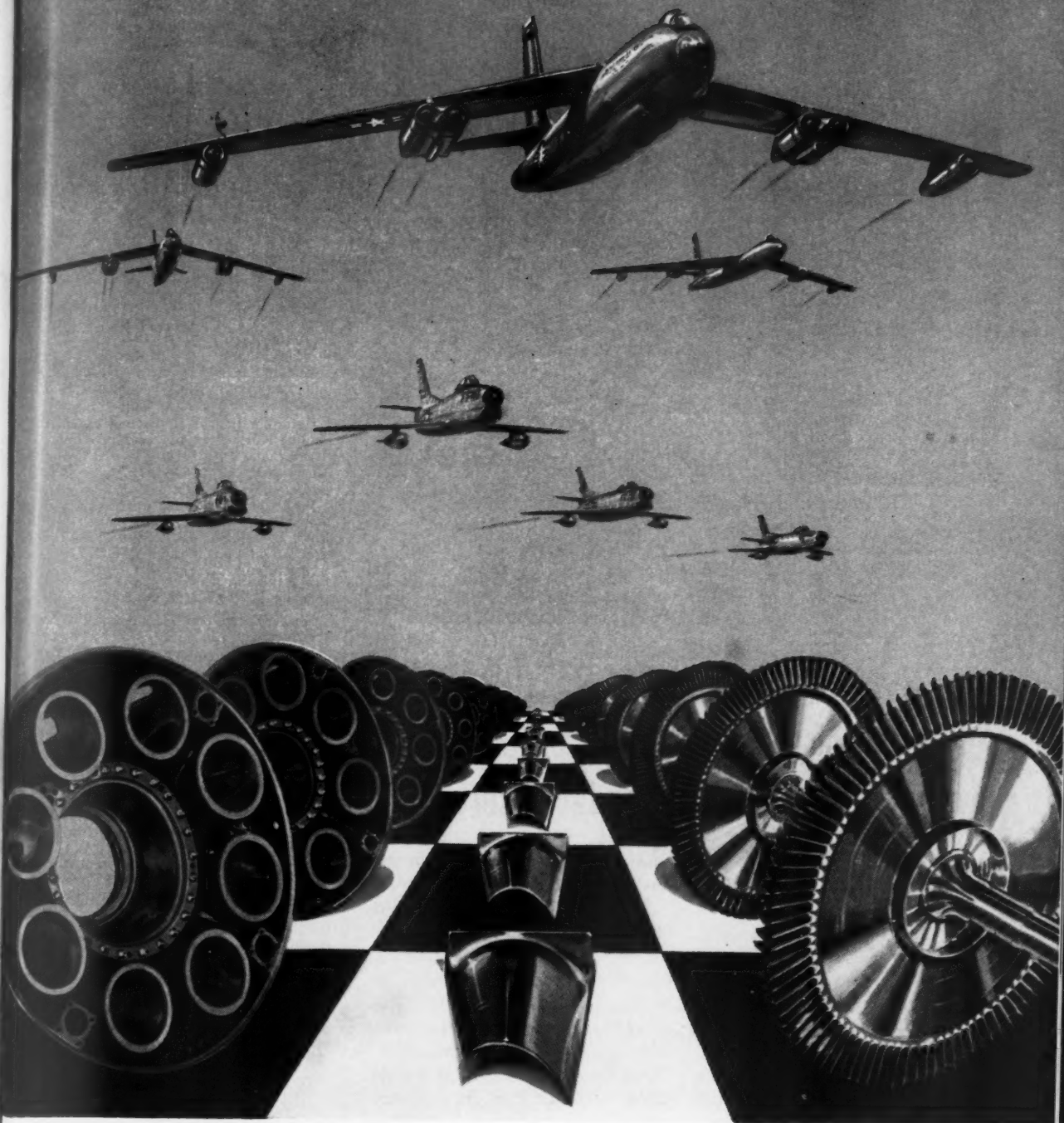
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sified from Confidential by authority of *NACA Res. Abstracts* 109, Nov. 20, 1956, p. 8.)

Ignition Delays of Alkyl Thiophosphites with White and Red Fuming Nitric Acids within Temperature Range 80° to -105°F., by Riley O. Miller and Dezzo J. Ladanyi, *NACA RM E52K25*, Feb. 1953, 24 pp. (Declassified from Confidential by authority of *NACA Res. Abstracts* 109, Nov. 20, 1956, p. 8.)

Evaluation of Ethyl Ether as an Ignition Aid for Turbojet Engine Fuels, by Edmund R. Jonash and Hampton H. Foster, *NACA RM E53I02*, Oct. 1953, 11 pp. (Declassified from Confidential by authority of *NACA Res. Abstracts* 109, Nov. 20, 1956, p. 9.)

The Cell Theory of Liquids, II, by J. A. Barker, *Proc. Royal Soc.*, vol. 237, Sept. 1956, pp. 63-74.

Rocket Refractories, by Harry B. Porter, *Naval Ord. Test Station*, Aug. 26, 1955, 48 pp. (Rep. No. NOTS 1191; NAVORD 4893).

Combustion of Boron, by Lloyd E. Line, Jr., *Experiment, Inc.*, Status Rep., Tech. Pub. 97, Apr. 1955, 29 pp.

Determination of Hydrofluoric Acid in Fuming Nitric Acid, by Hugh E. Malone, *Power Plant Lab. Wright Air Dev. Center*, April 1955, 11 pp. (WADC TN WCLP 55-155).

Properties of Fuming Nitric Acid, by Webster B. Kay, *Ohio State Univ., Research Foundation, Columbus, Ohio* (Report on Finishes and Materials Preservation and Corrosion and Corrosion Prevention, March 1954-Feb. 1955) Jan. 1956, 86 pp. (TR AFTR 6519, pt. 6).

Research on the Flammability Characteristics of Aircraft Fuels, by G. W. Jones, M. G. Zabetakis, and others, *Bur. Mines, Central Expt. Station* (WADC TR 52-35, Suppl. 3), 21 pp.

Studies on the Preparation of Aminoethylcellulose Perchlorate and other Fast-Burning Propellants, by Carl T. Lenk, Ribert J. Hartman, and Robert L. Schaaf, *Wyandotte Chemicals Corp. Summary Rep. No. 2*, March 1, 1955-March 1, 1956, May 1, 1956, 50 pp.

A Study of the Absorption Spectra and Ignition Limits of Exploding Mixtures of Carbon Disulfide and Oxygen, by Albert L. Myerson, Francis R. Taylor, and others, *Labs. Res. Dev. Franklin Inst.*, Report on Supporting Research on Aircraft Propulsion, March 1956, 107 pp. (TR WADC-TR-54-377).

Theoretical Performance of JP-4 Fuel and Liquid Oxygen as a Rocket Propellant, II, Equilibrium Composition, by Vearl N. Huff, Anthony Fortini, and Sanford Gordon, *NACA RM E56D23*, Sept. 1956, 47 pp.

Heat Transfer Characteristics of RFNA, *Bell Aircraft Corp. Rocket Engine Dept. Rep. 117-982-004*, July 1956, 140 pp.

Toxicity Studies on Hydrazine, Methylhydrazine, Symmetrical Dimethylhydrazine, Unsymmetrical Dimethylhydrazine and Dimethylnitrosamine, by Sidney Rothberg and Ogle B. Cope, *Chemical Warfare Labs. Army Chem. Center, Md.*, Apr. 25, 1955, 11 pp. (Rep. CWLR-2027).

Instrumentation and Experimental Techniques

An Investigation of the Time Response of the NGTE Sonic Pyrometer, by D. W. Willshire, *Gl. Brit. Nat. Gas Turbine Estab. Memo. M254*, Nov. 1955, 26 pp.

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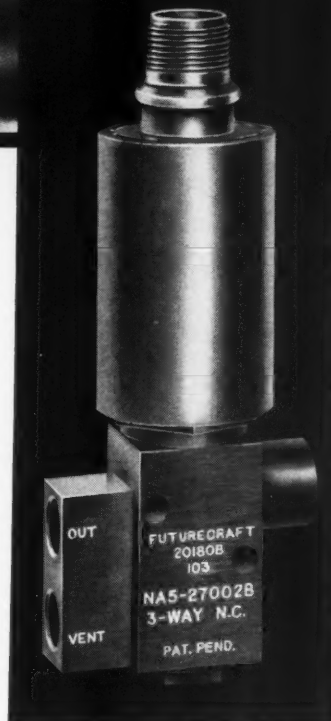
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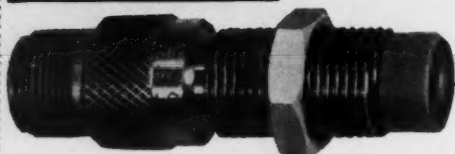


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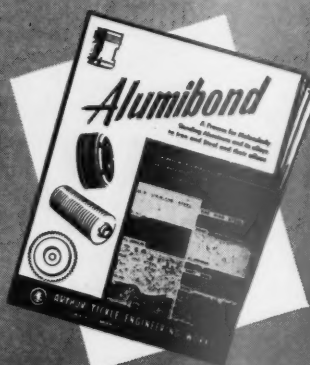
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rimeter and the Evaluation of a Method of Thermal Analysis for Obtaining the Specific Heat of Solids at High Temperatures, by Joseph Ambrose Rea, *Oklahoma A. and M. College, Thesis*, May 28, 1956, 52 pp.

A High Speed Oscillograph for Use in the Investigation of Explosive Phenomena, by E. P. Butt and J. D. Dunn, *Gt. Brit. Expl. Res. and Dev. Estab., TM 11/M/55*, March 1956, 44 pp.

Ships for Data Stations, *Aviation Week*, vol. 65, Oct. 1, 1956, p. 37.

Terrestrial Flight, Vehicle Design

Missiles at the Show, *Flight*, vol. 70, Sept. 1956, pp. 489-490.

Navy Plans 200-Mi. Rocket, *Aviation Week*, vol. 65, Oct. 1956, p. 29.

Key to Success in Guided Missiles, by Wernher von Braun, *Missiles and Rockets*, vol. 1, Oct. 1956, pp. 38-42.

How U. S. Tackles Problems of IRBM, ICBMs, by Erik Bergaust, *American Aviation*, vol. 20, Oct., 1956, pp. 113-116.

U. S. Missile Arsenal, *American Aviation*, vol. 20, Oct. 1956, p. 118.

Army Shows Missile Arsenal; Restone Near Field Use, by David A. Anderton, *Aviation Week*, vol. 65, Oct. 1956, pp. 50-52.

NACA's Mach 10 Rockets Air ICBM, by David A. Anderton, *Aviation Week*, vol. 65, Oct. 1956, p. 52-54.

Martin's Titan Project, by Henry T. Simmons, *Missiles and Rockets*, vol. 1, Oct. 1956, pp. 55-56.

Economics of Rocket-Propelled Air-Planes, Part II, by Robert Cornog, *Aeronautical Engng. Rev.*, vol. 15, Oct. 1956, pp. 49-58.

Space Flight, Astrophysics, and Aerophysics

Power Supplies and Telemetry for an Instrumented Artificial Satellite, *J. Brit. Interplanet. Soc.*, vol. 15, July-Aug. 1956, Part I, Orbital Considerations, by E. C. White, pp. 177-182; Part II, Instrumentation and Telemetry, by J. Foley, pp. 182-186; Part III, Availability of Power, by R. G. Wilkins, pp. 186-191.

The Potential Energy of a Small Rigid Body in the Gravitational Field of an Oblate Spheroid, by R. E. Roberson and D. Tatistcheff, *J. Franklin Inst.*, vol. 262, Sept. 1956, pp. 209-214.

Solid Propellants in Spaceships, by Wayne Proell, *J. Space Flight*, vol. 8, Sept. 1956, pp. 1-5.

Atomic Energy

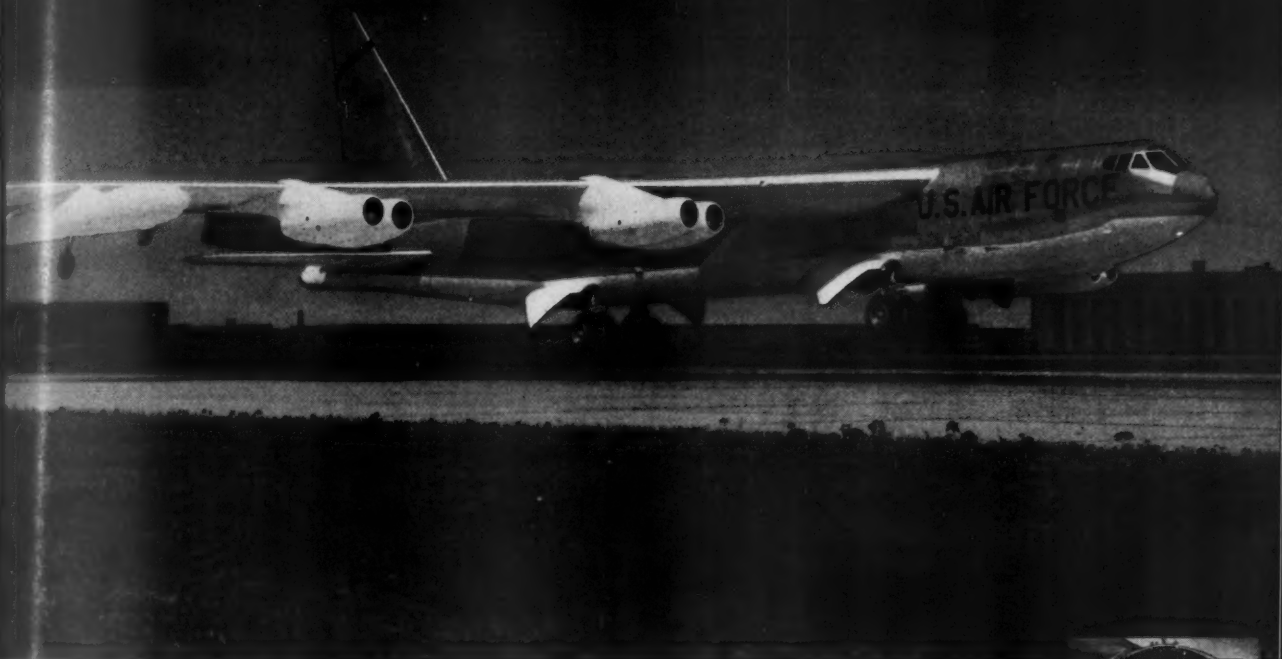
Thermodynamics of Working Gases in Atomic Rockets, by I. Sanger-Bredt, *J. Brit. Interplan. Soc.*, vol. 15, Sept.-Oct. 1956, pp. 233-248.

Possibilities of Electrical Space Ship Propulsion, by E. Stuhlinger, *Proc. 5th Intern. Astron. Congr.*, 1954, Vienna, Springer, 1955, pp. 100-119.

Basic Design Principles Applicable to Reaction Propelled Space Vehicles, by D. C. Romick, *Proc. 5th Intern. Astron. Congr.*, 1954, Vienna, Springer, 1955, pp. 81-99.

The Use of Nuclear Reactors for the Propulsion of Aircraft, by Gene E. Mad-dux, 1955 *First Award Papers, I.A.S. Student Branch Paper Competition*, New York, Institute of the Aeronautical Sciences, 1955, pp. 64-73.

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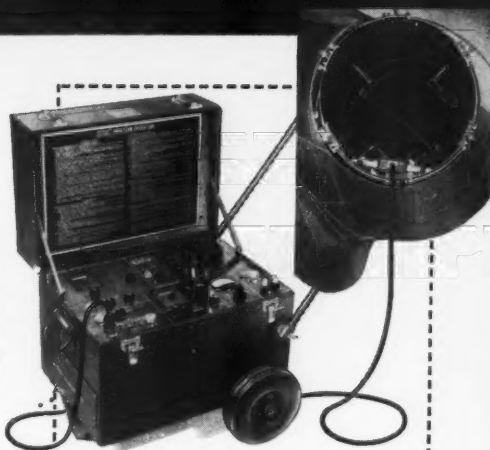
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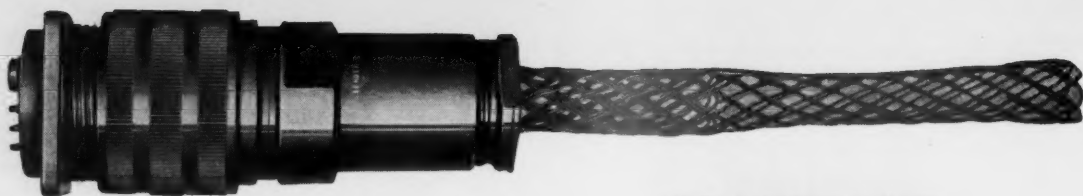
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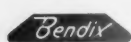
4. The cable-compressing gland used within the cable accessory accomplishes both a firm anchoring of the cable and effective waterproofing for multi-conductor cables. Neoprene sealing gaskets are used at every joint to insure a watertight connector assembly.

5. The cable accessory is designed to accommodate a Kellogg stainless steel wire strain relief grip for additional cable locking.

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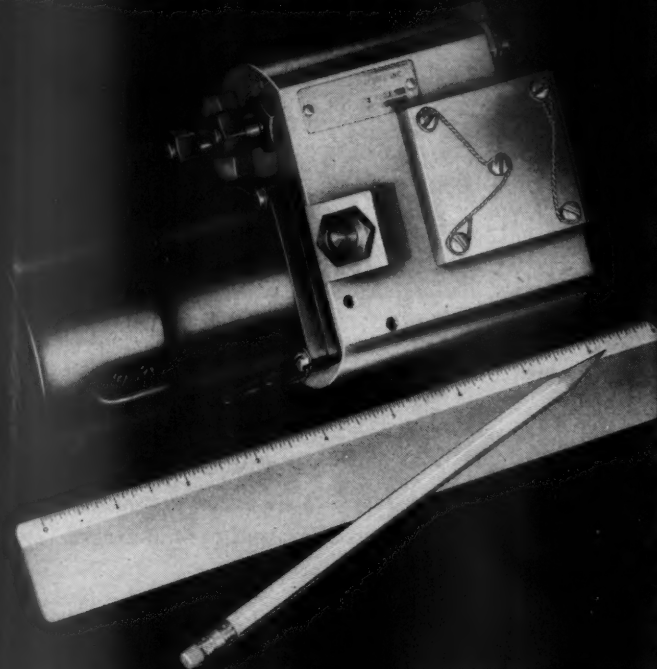
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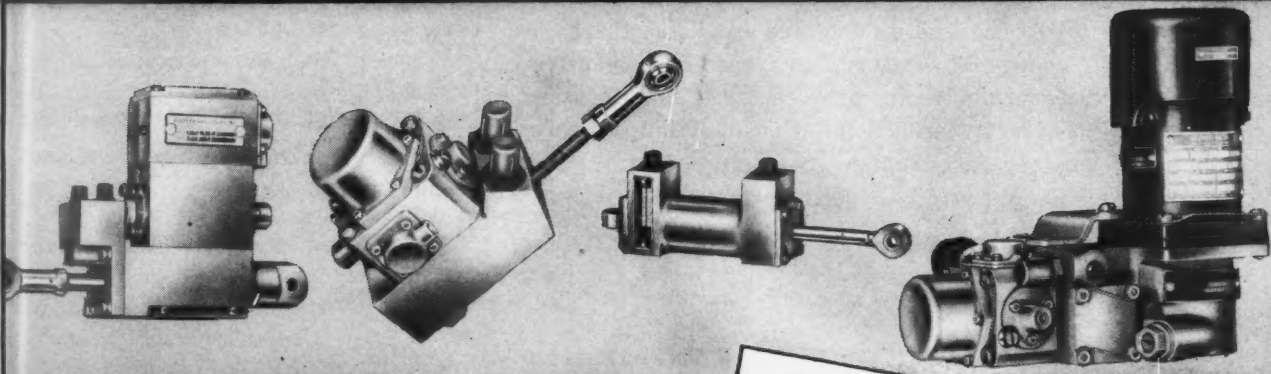
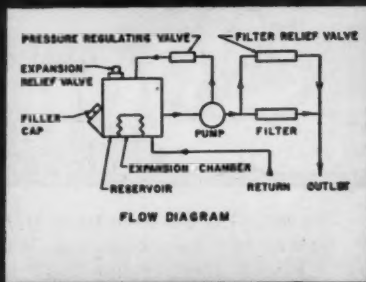
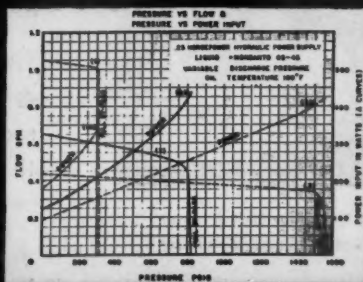
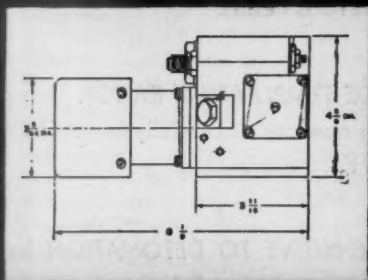
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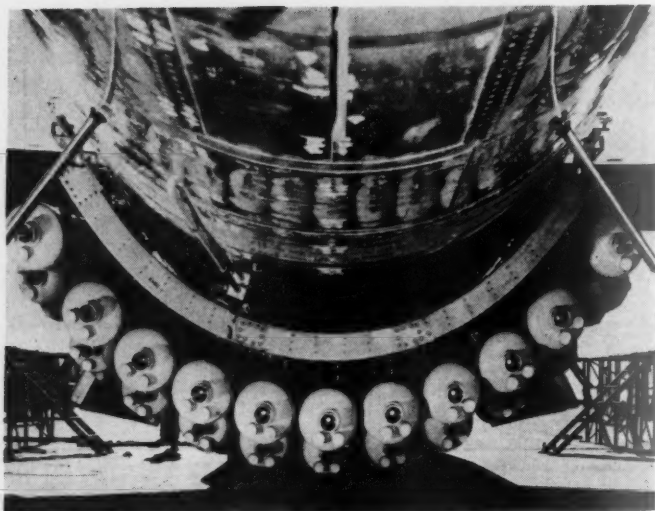
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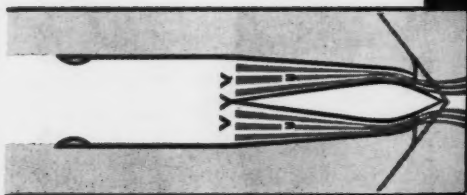
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